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MODULAR DEVELOPMENT PHASE MONITORING REPORT FOURTEEN

Volume 1 of 2

January – December 1984

Year End Report

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RIO BLANCO OIL SHALE COMPANY
MODULAR DEVELOPMENT PHASE
MONITORING REPORT 14

January - December 1984
YEAR-END REPORT

Prepared by:
RIO BLANCO OIL SHALE COMPANY
AURORA, COLORADO

May 31, 1985

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SECTION 1
INTRODUCTION

1.0 INTRODUCTION

The United States Department of the Interior/Geological Survey (USGS) initiated planning in 1969 for a prototype oil shale leasing program. Under this program, Gulf Oil Corporation and Standard Oil Company (Indiana) acquired the right to Federal Oil Shale Lease Tract C-a in Piceance Basin in northwest Colorado in April 1974. These two companies are developing Tract C-a under a general partnership called the Rio Blanco Oil Shale Company (RBOSC).

RBOSC has been engaged in extensive environmental data collection programs since its inception in 1974. Environmental baseline data were gathered between October 1974 and September 1976. An interim environmental monitoring program was conducted between September 1976 and August 1977, the period during which the Tract C-a lease was suspended. RBOSC initiated the Modular Development Phase (MDP) of tract development and the MDP Environmental Monitoring Program in August of 1977.

The MDP Environmental Monitoring Program is designed to provide data on air quality, visibility, terrestrial, ecology, aquatic ecology, hydrology, and specialized topics including ecological interrelationships. The program is designed based on the environmental stipulations in the Tract C-a lease, analysis of baseline and interim monitoring data, assessment of probable development impacts, and inputs from the BLM's Oil Shale Projects Office (OSPO). Monitoring is conducted according to the Lease Suspension Period Scope of Work (SOW), the current version of which (Revision 7.0) is dated January, 1983 and was approved by BLM's OSPO.

Data collected through the Environmental Monitoring Program are reported annually, in a year-end report to the OSPO. The first MDP monitoring report (Modular Development Phase Environmental Monitoring Report One, or MDP 1) was published in February 1978. Subsequent reports were published in September 1978, March and August 1979, March and August 1980, March and August 1981, April and September 1982, April and September 1983, and April 1984. This report is the fourteenth MDP Monitoring Report (MDP 14), and is the seventh year-end report. The MDP 14 report covers the 1984

reporting year (January 1- December 31, 1984). The report contains presentations and summaries of 1984 data; statistical comparisons between seasons, years, and location; and assessment of any development-related impacts. Sections of the report generally address objectives, methods, results and discussion, and summary and conclusions. Methods are referenced rather than fully described unless they are different from those employed in previous monitoring periods, need clarification, or have not been previously reported.

Major responsibility for implementation of the MDP monitoring program and preparation of the MDP reports rests with the staff of the RBOSC Environmental Affairs Department. However, several other individuals and entities assisted in monitoring activities during the 1984 reporting period. They include the following:

The Industrial Company (TIC) (Operational Hydrology Monitoring)
U. S. Geological Survey (Surface Water Gaging Station Data)
Cathedral Bluffs Shale Oil Company (Visibility Monitoring)
CORE Laboratories, Inc (Water Quality Sample Analysis)

Volume one of MDP 14 contains the following major sections:

Section 1	Introduction
Section 2	Atmospheric Studies
Section 3	Terrestrial Studies
Section 4	Aquatic Studies
Section 5	Hydrology Studies
Section 6	Special Studies/Ecological Interrelationships

Volume two of MDP 14 contains the following appendices:

Appendix 2	Air Quality and Meteorological Data
Appendix 3	Vegetation and Fauna Data and Analyses
Appendix 4	Aquatic Abiotic and Biotic and Analyses
Appendix 5	Hydrological Data and Analyses
Appendix 6	Special Studies and Ecological Interrelationships Data and Analyses

SECTION 2
ATMOSPHERIC STUDIES

2.0 INTRODUCTION

The Tract C-a atmospheric studies program consists of two elements: (1) measurements of total suspended particulate matter and certain gaseous chemical compounds, and (2) measurements of selected meteorological parameters. The monitoring locations were originally established to measure the ambient air quality generally upwind and somewhat removed from the expected tract development, and at points where tract development might have an effect on the air quality. Simultaneous meteorological measurements are being made to allow for the prediction of the dispersion of emissions resulting from tract development.

Air quality and meteorological data have been obtained since February 1975 from monitoring instruments located on or near Tract C-a. Data collected during the first two years of monitoring make up the baseline data set. Data from the baseline period were obtained at four locations around the tract. Following the baseline period, an interim data acquisition program was established to cover an interval during which the tract development lease conditions were modified and partially suspended. During the interim period (February through August 1977), a single air quality and meteorological monitoring station was operated to maintain data continuity. The system was expanded to three meteorological and two air quality monitoring stations for the active Modified In-Situ (MIS) retorting stage of the Modular Development Phase.

Following completion of the MIS retorting program, activity on the tract has decreased to a very low level. The monitoring program has been reduced accordingly, and has been measuring essentially background ambient air quality. Consequently, the ambient air quality monitors were shut down on July 1, 1984, with approval of the Oil Shale Project Office of the Bureau of Land Management. The meteorological and particulate monitoring program is still in operation (Table 2-1).

Table 2-1. Air Studies Monitoring Parameters and Schedule for 1984, Tract C-a

Parameter	Location	Start Date	Frequency
Sulfur Dioxide	Site 1	Feb. 1975	Continuous[1/]
Hydrogen Sulfide	Site 1	Feb. 1975	Continuous[1/]
Nitric Oxide	Site 1	Feb. 1975	Continuous[1/]
Nitrogen Oxides	Site 1	Feb. 1975	Continuous[1/]
Ozone	Site 1	Feb. 1975	Continuous[1/]
Carbon Monoxide	Site 1	Feb. 1975	Continuous[1/]
Total Suspended Particulates	Sites 1,3	Feb. 1975	Every 4th Day
Wind speed (10m)	Site 1	Feb. 1975	Continuous
Wind speed (60m)	Site 1	Feb. 1975	Continuous
Wind direction (10m)	Site 1	Feb. 1975	Continuous
Wind direction (60m)	Site 1	Feb. 1975	Continuous
Wind sigma	Site 1	Sept. 1981	Continuous
Ambient temperature (10m)	Site 1	Feb. 1975	Continuous
Temperature differential (10-60m)	Site 1	Feb. 1975	Continuous
Precipitation	Sites 1, 3	Feb. 1975	By event
Snow depth and accumulation	Sites 1, 3	Nov. 1978	By event
Solar radiation	Site 1	Feb. 1975	Continuous
Visibility	Visibility Shelter	Spring 1978	Semi-annually

1/ These monitors were shut down on July 1, 1984.

2.1 AIR QUALITY

Air quality monitoring has been conducted on and near Tract C-a to measure the concentrations of certain pollutants which may be emitted by tract operations. The ambient air quality monitoring network consists of one location where gaseous constituents have been measured (Site 1) and two locations where Total Suspended Particulates (TSP) are measured (Sites 1 and 3). Site 1 is located just west of the tract and generally measures background ambient air quality, while Site 3 is located east of the tract in a broad gulch that drains much of the tract. Under the minimum activity conditions of the lease suspension period, which began in 1982, Site 3 also measures primarily background particulate concentrations. The Site 1 air quality monitors were shut down on July 1, 1984, with approval of the Oil Shale Project Office of the Bureau of Land Management.

All of the air quality data, with the exception of the TSP data, have been collected by automatic monitoring equipment and recorded by a data acquisition system on digital computer tape and backup strip charts. The data on the digital tape are recorded as hourly values. Plots of air quality data collected during 1984 are presented in Appendix 2-1.1. Hi-Vol monitors are used to collect 24-hour samples of TSP concentrations every fourth day.

A visibility study (in cooperation with Federal Oil Shale Lease Tract C-b) has been conducted each spring and fall since 1978 as part of the air studies program.

As part of the year-end report, an extensive analysis has been carried out on the data collected in 1984. Where appropriate, comparisons have been made among the data from 1984, the baseline period (February 1975-January 1977), and the seven previous years of the MDP period (1978, 1979, 1980, 1981, 1982 and 1984).

When analyzing a data set, it is important to evaluate the data in relation to the limitations of the instrumentation. This is particularly true of air quality data gathered in a near-pristine environment such as Tract C-a.

Ambient concentrations of several gaseous constituents usually are at or below the minimum measurement capability of air quality monitoring instruments. Statistical analyses may therefore not be applicable to these data sets.

A quantitative measure has been developed to use as a conservative minimum level, below which there is essentially no probability that the values represent real and valid data. This level, called the threshold of detection, is defined as twice the noise level of the instrument. The threshold of detection can thus be used to determine if there is a sufficient number of valid data points to warrant further statistical analyses.

It should be emphasized that the threshold of detection is a conservative measure to use in determining data validity. It is designed to take into account the errors or uncertainties which develop when measurements are taken near the minimum detectable limit of any monitor. These uncertainties are extremely difficult to quantify, but it is quite likely that the threshold of detection as defined above represents the instruments and data acquisition system in an optimal condition. Consequently, this value, determined independently for each instrument, is a conservative measure of data validity. That is, some data that are not significant (within the noise of the measurement system) may be retained, but no valid data will be arbitrarily discarded (due to a detection limit set too high).

The ultimate goal is to define confidence limits around the data collected by each instrument, which will serve as realistic criteria with which to judge the validity of the data. Threshold of detection values for each instrument are given in Table 2-2. These detection limits can be used as a guide to determine how much of the data can be considered valid for statistical analysis. The significance of the data for each parameter will be discussed separately in the appropriate sections below. In several instances, the data sets are at or below the minimum detectable limit of the instrument, which limits the analysis that are warranted.

Table 2-2. Air Quality Instrumentation used at Tract C-a, with the Threshold of Detection for each Monitor

Parameter	Manufacturer	Model	Technique	Threshold of Detection (ppm)
SO_2	Thermo Electron Corporation	43	Pulsed Fluorescence	0.002
H_2S	Thermo Electron Corporation	45	Pulsed Fluorescence	0.002
NO/NO_x	Bendix	8101-B	Chemiluminescence	0.005
Photochemical Oxidant (O_3)	Bendix	8002	Chemiluminescence	0.001
CO	Thermo Electron Corporation	48	Gas Filter Correlation Spectroscopy	0.5

A. Sulfur Dioxide

1. Objectives

The objective of monitoring for sulfur dioxide is to establish the ambient air concentration prior to and during tract development. The existing sulfur dioxide levels and associated environmental effects can be used as a basis for assessing future environmental changes that may be related to any increase in the concentration of sulfur dioxide.

2. Methods

The methods followed for collection of sulfur dioxide data were described in RBOSC MDP Monitoring Report 5 (RBOSC 1980).

3. Results and Discussion

Table 2-3 provides mean, maximum, and minimum concentrations of air quality parameters monitored at Tract C-a during the first six months of 1984. The table shows that the maximum hourly concentration of sulfur dioxide measured at Site 1 was 0.003 ppm, while the mean concentration was 0.002 ppm, which is at or below the threshold of detection of the instrument. Most of the sulfur dioxide concentrations monitored during the first six months of 1984 were at or below the threshold of detection for the instruments.

Comparison of these data (Table 2-3) with data from earlier years (1983, Table 2-4; February 1975-January 1977, Table 2-5) show that maximum and average sulfur dioxide concentrations have been similar during each of the years. The maximum hourly sulfur dioxide concentration in 1983 was 0.008 ppm. During the baseline period, the maximum concentration of 0.09 ppm was at least partially the result of less accurate and sophisticated instrumentation. The yearly means during both the baseline and MDP periods have been at or below the threshold of detection of the monitoring equipment.

Table 2-3. Six-Month Summary of Air Quality Data Collected from January to June 1984, Tract C-a

Parameter	Units	Minimum[1/]	Maximum[1/]	Arithmetic Mean
		Site 1		
SO_2	ppm	0.002	0.003	0.002
H_2S	ppm	0.002	0.006	0.002
NO	ppm	0.005	0.006	0.005
NO_x	ppm	0.005	0.005	0.005
O_3	ppm	0.026	0.077	0.045
CO	ppm	0.5	0.5	0.5
TSP[3/]	ug/m^3	0	40	9 [2/]
		Site 3		
TSP[3/]	ug/m^3	0	41	8 [2/]

1/ Hourly Average

2/ Geometric Mean

3/ 24-hour Averages

Table 2-4. Summary of Air Quality Data Collected from January to December 1983, Tract C-a

Parameter	Units	Minimum[1/]	Maximum[1/]	Arithmetic Mean
		Site 1		
SO_2	ppm	0.002	0.008	0.002
H_2S	ppm	0.002	0.007	0.002
NO	ppm	0.005	0.008	0.005
NO_x	ppm	0.005	0.008	0.005
O_3	ppm	0.015	0.073	0.042
CO	ppm	0.5	0.5	0.5
TSP[3/]	ug/m^3	0	92	9 [2/]
		Site 3		
TSP[3/]	ug/m^3	1	56	8

1/ Hourly Average

2/ Geometric Mean

3/ 24-hour Averages

Table 2-5. Summary of Air Quality Data Collected from February 1975 to January 1977 (Baseline Period), Tract C-a

Parameter	Units	Minimum[1/]	Maximum[1/]	Arithmetic Mean
		Site 1		
SO_2	ppm	0.000	0.09	0.01
H_2S	ppm	0.000	0.05	0.01
NO	ppm	0.000	0.237	0.008
NO_x	ppm	0.000	0.234	0.009
O_3	ppm	0.000	0.068	0.034
CO	ppm	0.0005	4.2	0.6
TSP[3/]	ug/m^3	1	211	9 [2/]
		Site 3		
TSP[3/]	ug/m^3	1	79	15 [2/]

1/ Hourly Average

2/ Geometric Mean

3/ 24-hour Averages

B. Hydrogen Sulfide

1. Objectives

The objective of monitoring hydrogen sulfide in the ambient air on the tract is to establish the background value. Tract development, which will involve recovery of sulfur-bearing organics, may release hydrogen sulfide into the ambient air. Future concentrations of this constituent may be compared to pre-development conditions to assess environmental impacts.

2. Methods

The methods for collection of hydrogen sulfide data were described in RBOSC MDP Monitoring Report 5 (RBOSC 1980).

3. Results and Discussion

Table 2-3 shows that the maximum concentration of hydrogen sulfide at Site 1 during the first six months of 1984 was 0.006 ppm. The mean concentration for this data period was 0.002 ppm, at or below the threshold of detection of the instrument. Comparisons with previous data show that the maximum concentrations have been low, while the mean annual concentrations have remained at or below the threshold of detection.

C. Oxides of Nitrogen

1. Objectives

Oxides of nitrogen are monitored to establish the existing natural background levels prior to major tract development and operation. Tract operations will involve substantial combustion of various fuels with the resultant generation of oxides of nitrogen. Nitric oxide in the presence of sunlight and hydrocarbons may be a mechanism for smog production.

2. Methods

The methods followed for collection of oxides of nitrogen data were described in MDP Monitoring Report 2 (RBOSC 1978).

3. Results and Discussion

The concentrations of both nitric oxide and total oxides of nitrogen were below the threshold of detection most of the time during the first six months of 1984, resulting in a mean concentration for this data period of both these variables at or below 0.005 ppm. These values are similar to those obtained during previous years--no annual mean for either nitric oxide or total oxides of nitrogen has exceeded 0.01 ppm. The maximum concentrations measured during 1984 were 0.006 ppm for both nitric oxide and 0.005 ppm for total oxides of nitrogen.

D. Carbon Monoxide

Carbon monoxide is produced by incomplete oxidation of carbon during combustion. Vehicular use and fuel combustion during tract development may result in the emission of carbon monoxide in the tract area.

1. Objectives

Carbon monoxide is monitored to establish the ambient air concentration of this constituent prior to and during tract development activities.

2. Methods

The methods followed for collection of carbon monoxide data were described in MDP Monitoring Report 2 (RBOSC 1978).

3. Results and Discussion

The measured concentration of carbon monoxide at Site 1 was at or below the threshold of detection most of the time. Both the maximum concentration and mean concentration during the first six months of 1984 were 0.5 ppm. These results are very similar to those of previous years.

E. Ozone

1. Objectives

Ozone monitoring is conducted to determine the ambient air concentration of this constituent prior to and during tract development and operation. The potential emissions of oxides of nitrogen coupled with hydrocarbons in strong sunlight can produce photochemical reactions leading to the formation of ozone.

2. Methods

The methods followed for collection of ozone data were described in RBOSC MDP Monitoring Report 2 (RBOSC 1978).

3. Results and Discussion

The range of ozone concentrations recorded during the first six months of 1984 at Site 1, as shown in Table 2-3, was 0.026 to 0.077 ppm. The mean concentration of ozone during this period was 0.045 ppm. Thus, there were no violations of the primary or secondary National Ambient Air Quality Standard (NAAQS) for ozone (0.12 ppm). These concentrations are comparable to those found during the previous monitoring periods (Tables 2-4 through 2-5).

Previous year-end reports contained discussions related to the common phenomenon of relatively high concentrations of ozone occurring at remote

sites such as Tract C-a. The conclusion, based on analysis of the site data and research done at other rural sites, was that these relatively high concentrations may be due to a number of factors, including stratospheric injection, photochemical reactions, or long-range transport. The concept of local production of ozone as an important factor to date has not been supported by the observed events.

F. Particulates

1. Objectives

The objectives of total suspended particulate (TSP) monitoring are to establish a natural background TSP concentration and to monitor the effects of tract development on TSP concentrations.

2. Methods

The methods followed for collection of TSP data were described in MDP Monitoring Report 4 (RBOSC 1979b).

3. Results and Discussion

Quarterly and annual geometric mean and maximum values of the TSP data for 1984 at Sites 1 and 3 are presented in Table 2-6. The highest 24-hour concentration, 41 ug/m^3, was measured in early September at Site 3. This value is well below the 24-hour secondary National Ambient Air Quality Standard (NAAQS) for TSP of 150 ug/m^3. Annual geometric means for 1984 were 7 ug/m^3 at Site 1 and 8 ug/m^3 at Site 3. These values are far below the annual secondary NAAQS for TSP of 60 ug/m^3.

The quarterly and annual geometric means and maximum TSP concentrations for 1983 and the baseline period are presented in Tables 2-7 and 2-8 for comparison. The tables show that the geometric mean annual TSP concentration at Site 1 decreased slightly from 1983 to 1984 (from 9 to 7 ug/m^3), while

Table 2-6. Quarterly and Annual Geometric Means and Maximum Values of 24-hour Average Total Suspended Particulate Concentrations (ug/m^3) during 1984 on Tract C-a

	Site 1	Site 3
Winter 1984 (Jan, Feb, Dec)		
Geometric Mean	3	3
Maximum	10	13
Spring 1984 (March-May)		
Geometric Mean	7	8
Maximum	28	31
Summer 1984 (June-August)		
Geometric Mean	15	15
Maximum	26	40
Fall 1984 (September-November)		
Geometric Mean	8	8
Maximum	24	41
1984 Annual		
Geometric Mean	7	8
Maximum	28	41

Table 2-7. Quarterly and Annual Geometric Means and Maximum Values of 24-hour Average Total Suspended Particulate Concentrations (ug/m^3) during 1983 on Tract C-a

	Site 1	Site 3
Winter 1983 (Jan, Feb, Dec)		
Geometric Mean	4	4
Maximum	10	8
Spring 1983 (March-May)		
Geometric Mean	7	6
Maximum	22	18
Summer 1983 (June-August)		
Geometric Mean	17	20
Maximum	92	56
Fall 1983 (September-November)		
Geometric Mean	8	10
Maximum	27	49
1983 Annual		
Geometric Mean	9	8
Maximum	92	56

Table 2-8. Quarterly and Annual Geometric Means and Maximum Values of 24-hour Average Total Suspended Particulate Concentrations for the Baseline Period (February 1975 to January 1977) (ug/m^3) on Tract C-a

	Site 1	Site 3
February 1975		
Geometric Mean	--	5
Maximum	--	12
Spring 1975 (March-May)		
Geometric Mean	29	23
Maximum	95	163
Summer 1975 (June-August)		
Geometric Mean	22	47
Maximum	211	247
Fall 1975 (Sep-Nov)		
Geometric Mean	6	18
Maximum	52	137
Winter 1975-76 (Dec-Feb)		
Geometric Mean	2	4
Maximum	10	14
Spring 1976 (March-May)		
Geometric Mean	11	11
Maximum	80	130
Summer 1976 (June-August)		
Geometric Mean	22	27
Maximum	81	105
Fall 1976 (Sep-Nov)		
Geometric Mean	12	35
Maximum	53	281
Winter 1976-1977 (Dec-Jan)		
Geometric Mean	5	5
Maximum	18	59
1975-76 Annual		
Geometric Mean	9	18
Maximum	211	247
1976-77 Annual		
Geometric Mean	8	12
Maximum	81	281

Site 3 showed no change in the mean annual concentration. These averages are similar to the averages for the baseline, which were 8 and 9 ug/m^3 during the two-year baseline period. These data reflect the low level of activity at the tract.

The geometric mean annual TSP concentrations at Site 3, located generally downwind of the tract development area, have been higher than the mean annual TSP concentrations at Site 1 for much of the entire period of record, even during the baseline period. However, in 1983 and 1984, the annual mean TSP concentrations at Sites 1 and 3 have been roughly equal and at a very low level, approximately 8 ug/m^3. This is likely a result not only of the reduced activity on the tract, but also a reduction in the general activity in the area (e.g., less oil and gas drilling).

The annual cumulative frequency distributions of the TSP concentrations at both sites are presented in Figure 2-1. The distributions for Sites 1 and 3 are similar. The figure shows that the 50 percent probability points for the TSP concentrations in 1984 are 8 ug/m^3 for Site 1 and 7 ug/m^3 for Site 3. These are identical to the results obtained in 1983. The 50 percent probability concentrations obtained for the baseline period, 10 ug/m^3 for Site 1 and 22 ug/m^3 for Site 3, are similar to the 1984 data at Site 1 but considerably higher at Site 3.

Correlation Analysis

Table 2-9 provides the correlation coefficient (r) and the coefficient of determination (r^2) between Sites 1 and 3 for the TSP concentrations. The correlations were computed on an annual data set for each of the two baseline years (1975-77) and the six developmental years starting in 1979. The correlations between the two sites were lowest for the baseline years, and have increased to a range of 0.8-0.9 during the last five years. No rationale for the relatively low correlations during the baseline years has been developed.

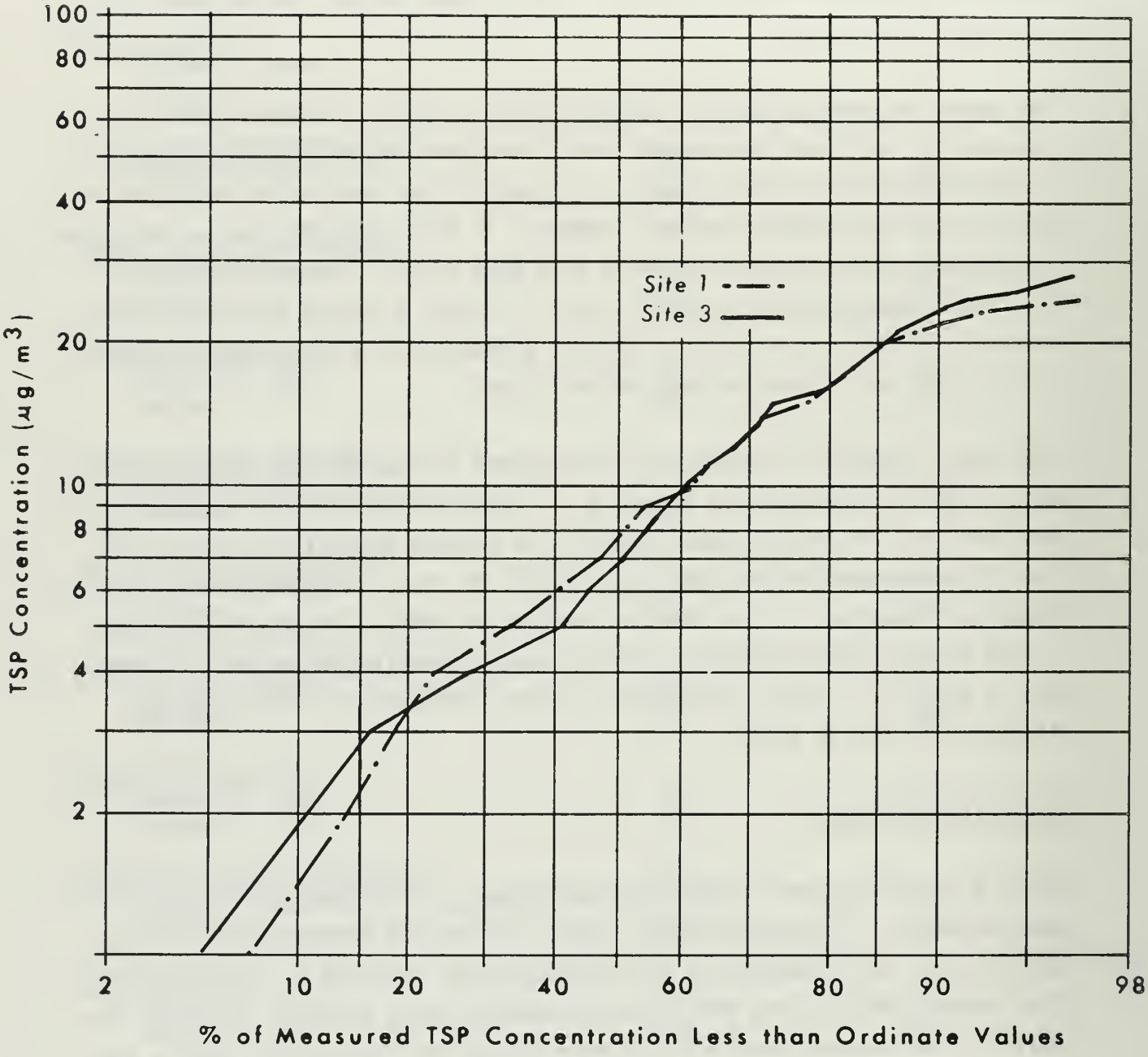

Figure 2-1. Cumulative Frequency Distributions of Total Suspended Particulate (TSP) from the Two Tract C-a Monitoring Sites, January-December, 1984.

Table 2-9. Correlation Coefficients (r) and Coefficients of Determination (r^2) for the 24-hour Average Total Suspended Particulate Concentrations between Sites 1 and 3 during 1984, Tract C-a

Period	Correlation Between Sites 1 and 3 r	r^2
Baseline		
2/75 - 1/76	0.31	0.10
2/76 - 1/77	0.49	0.24
Modular Development Phase		
1979	0.60	0.36
1980	0.83	0.69
1981	0.85	0.72
1982	0.90	0.81
1983	0.83	0.70
1984	0.86	0.73

The sample sizes for these correlations range from 72 to 115.

The correlations for 1984 are quite high, since the coefficient of determination given in Table 2-9 for Sites 1 and 3 (r^2) shows that 73 percent of the annual variation in TSP concentration at Site 1 is associated with the variations at Site 3. The similarity in the patterns of TSP concentrations appear to reflect primarily regional rather than localized influences. With the current low activity levels in the area, there are relatively few localized sources affecting the TSP concentrations.

Additional analyses of the TSP data are presented in Section 6.5, in conjunction with a special study of inhalable particulate data (PM_{10} and PM_6) collected concurrently with the TSP data at Tract C-a.

2.2 METEOROLOGY

Meteorological parameters are monitored to provide information on the general climate of Tract C-a and vicinity. They will also provide a basis for estimating the potential impact of emissions that may result from tract development and operation. One meteorological monitoring site was in operation during 1984. Meteorological data were taken at the 10-m and 60-m levels at Site 1. The parameters measured at this site are given in Table 2-1. Site 1 is at an elevation of 7,335 feet above mean sea level (MSL), and is located just west of the tract boundary. This section of the report deals primarily with the meteorological data collected during the period January-December 1984. Precipitation data and snow depth measurements are presented in Appendices 2-2.2 and 2-2.3, respectively. Barometric pressure data are presented in Appendix 2-2.4. The data for the baseline period and the previous years of the MDP period were extracted from earlier reports (RBOSP 1977, RBOSC MDP Monitoring Report 3, RBOSC MDP Monitoring Report 5, RBOSC MDP Monitoring Report 7, RBOSC MDP Monitoring Report 9, RBOSC MDP Monitoring Report 11 and RBOSC MDP Monitoring Report 13) for comparison purposes. Plots of meteorological data collected from continuous monitoring instruments are presented in Appendix 2-2.1.

A. Temperature and Stability

1. Objectives

Ambient air temperature, a primary climatic parameter, provides basic information on monthly and year-to-year variability of climatic conditions at Tract C-a. The measured vertical temperature differential within the lowest boundary layers is a measure of the stability of the atmosphere. Atmospheric stability strongly influences the dispersion of emissions into the atmosphere, and is therefore an important input into air quality models.

2. Methods

The methods followed for collection of temperature data were described in MDP Monitoring Report 3 (RBOSC 1979a).

3. Results and Discussions

Table 2-10 presents a summary of monthly, seasonal, and annual temperature statistics for 1984 at Site 1 (10-m level). The temperature statistics presented for this site include means, average daily maxima, average daily minima, absolute maxima, and absolute minima.

The mean annual temperature was 5.9°C at Site 1, which is the lowest mean temperature during the nine-year period of record (by 0.2°C). The absolute maximum temperature recorded during the year was also lower than previous years. The extreme temperatures recorded at the tract during 1984 were 27.7°C and -21.7°C.

The temperature record allows the calculation of the length of the frost-free period at the site. This information is helpful in determining the required hardiness and suitability of plants that will be used in revegetation of the tract. However, it should be noted that these temperatures are measured at 10-m above ground level, so that the first and last excursion below 0 °C at 10-m (as used here) probably represents a "hard frost" at the ground surface.

Table 2-11 presents the frost-free period for the nine years at Site 1. The table also provides the 1980-1983 frost-free period for several climatological stations located in the vicinity of the tract. It should be noted that the National Weather Service stations measure the temperature at 2 meters, so the data are not strictly comparable to the data taken at the tract. However, they are included for reference.

Table 2-10. Monthly, Seasonal, and Annual Summary of Temperatures (°C) (Mean, Average Daily Maximum, Average Daily Minimum, Absolute Maximum, Absolute Minimum), January-December 1984, Level of Site 1 10-m Level, Tract C-a.

Period	Mean	Avg Daily Max	Avg Daily Min	Abs Max	Abs Min
January	-5.7	-2.5	-9.0	4.5	-21.7
February	-3.9	-0.2	-7.1	6.2	-12.3
March	-1.3	2.3	-4.9	9.7	-14.6
April	2.2	6.3	-1.8	18.2	-11.2
May	12.3	21.9	7.2	24.8	-4.1
June	14.4	18.9	9.8	27.0	0.4
July	19.6	24.2	14.9	27.7	12.1
August	18.7	22.8	14.7	26.6	11.2
September	13.7	18.4	9.2	25.5	-2.8
October	3.7	7.3	0.5	16.1	-7.0
November	1.1	4.6	-2.3	11.8	-11.7
December	-3.6	-0.5	-6.7	7.8	-13.5
Seasonal					
Winter (Dec, Jan, Feb)	-4.4	-1.1	-7.6	7.8	-21.7
Spring (Mar, Apr, May)	4.4	10.2	0.2	24.8	-14.6
Summer (Jun, July, Aug)	17.6	22.0	13.1	27.7	0.4
Fall (Sept, Oct, Nov)	6.2	10.1	2.5	25.5	-11.7
Annual	5.9	10.3	2.0	27.7	-21.7

Table 2-11. Frost-free Period for Site 1 during the Period of Record, and the Frost-free Period During Recent Years for Selected Climatological Stations.

	Frost-Free Period							
	Site 1		Meeker		Little Hills		Grand Junction	
Year	Length (Days)	Dates	Length (Days)	Dates	Length (Days)	Dates	Length (Days)	Dates
1984	140	05/07-09/24	106	06/11-09/25	78	06/22-09/08	178	04/29-10/24
1983	124	05/18-09/19 1/	98	06/14-09/20			206	04/17-11/09
1982	147	05/11-10/05	114	06/09-10/01			173	04/21-10/11
1981	156	05/13-10/16	118	06/16-10/12			202	04/06-10/25
1980	144	05/25-10/16	101	06/02-09/11			192	04/14-10/23
1979	133	06/09-10/20						
1978	111	05/31-09/19						
1976	112	06/14-10/04						
1975	132	05/29-10/08						

1/ Estimated due to lightning strike on tower during this period.

The table shows that the frost-free period at Site 1 has ranged from 111 to 156 days over the nine years of record. The last frost date in the spring at the Tract is quite late, averaging around the last week in May. The first frost date in the fall ranges from mid-September to mid-October.

The frost-free periods at Meeker and Rangely are somewhat shorter than on the Tract (probably due to the difference in height above ground level that measurements are taken), but at Grand Junction the period is significantly longer. This is probably a function primarily of Grand Junction's lower elevation (4800 ft. vs. 7300 ft. at Site 1).

Table 2-12 provides a summary of annual absolute minimum, absolute maximum, and mean values of the air temperature recorded at Site 1 during each of the nine years of data collected to date. There appears to have been no consistent trend during the period of record.

B. Wind Speed and Wind Direction

1. Objectives

The wind speed and wind direction influence atmospheric dispersion. Measurement of the frequency of occurrence of wind speed and wind direction classes can also be used in interpreting air quality data.

2. Methods

The methods followed for collection of wind data were described in MDP Monitoring Report 3 (RBOSC 1979a).

3. Results and Discussion

Seasonal and annual wind roses for each of the three sites for the current year are presented in Figures 2-2 to 2-5.

Table 2-12. Summary of Annual and Combined Nine-Year Onsite Climatology of Absolute Minimum, Absolute Maximum and Mean Temperatures (^{o}C) During the Baseline and MDP Periods, Tract C-a.

Temperatures[1/]	2/75-1/76	2/76-1/77	1978	1979	1980	1981	1982	1983	1984	Combined 8-Year Data Set
Site 1 (10-m level)										
Absolute Minimum	-21.1	-21.7	-24.0	-24.6	-15.5	-19.9	-26.2	-22.6	-21.7	-26.2
Absolute Maximum	30.1	29.7	30.4	28.5	28.0	29.7	29.4	29.0	27.7	30.4
Mean	6.1	7.2	7.1	6.6	7.6	8.0	6.2	6.7	5.9	6.8

1/ Minimum and maximum annual temperatures are based on hourly average values for each 1-year period.

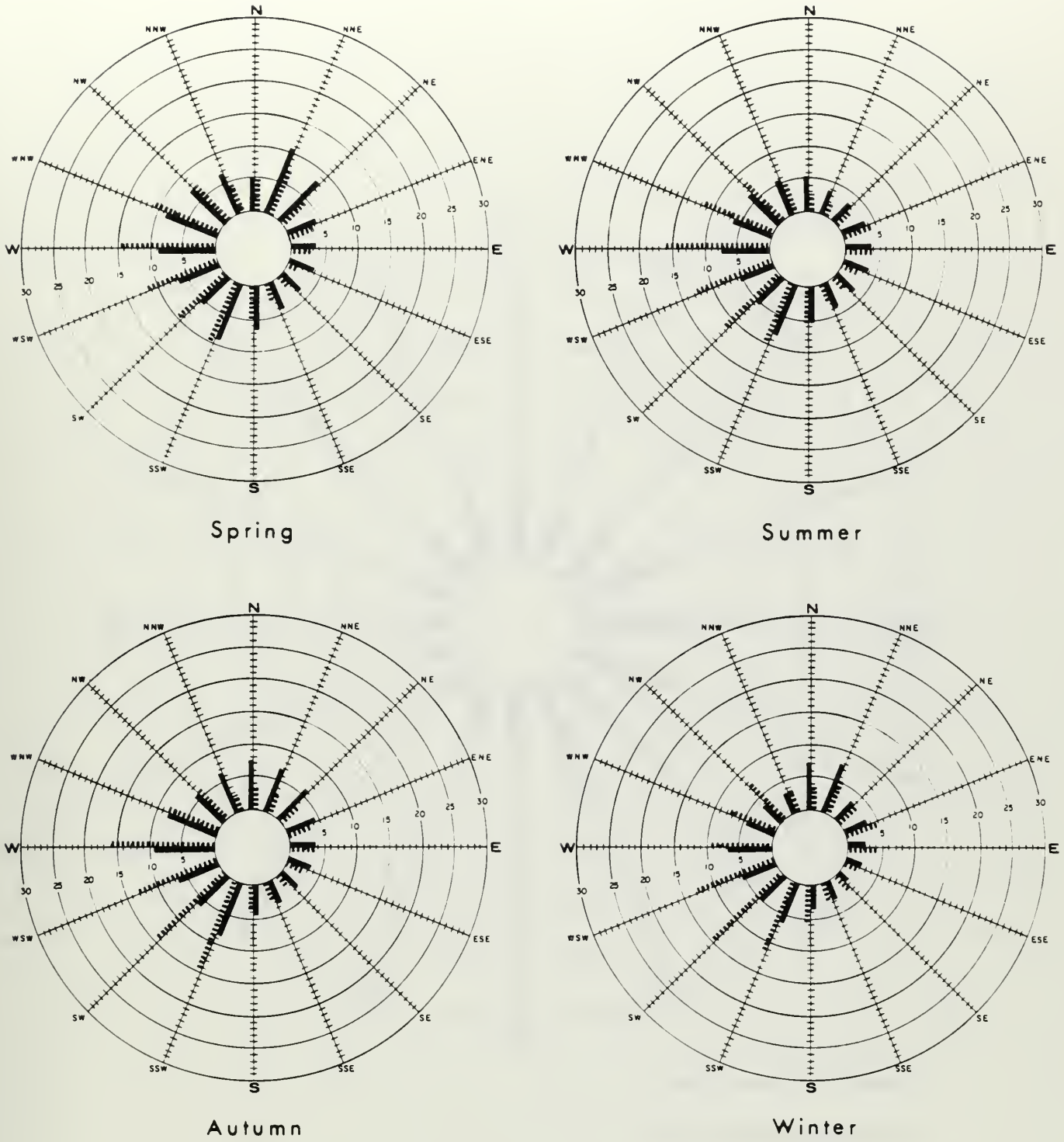

Figure 2-2 Seasonal Wind Roses, January-December 1984, Site 1, 10-m Level, Tract C-a.

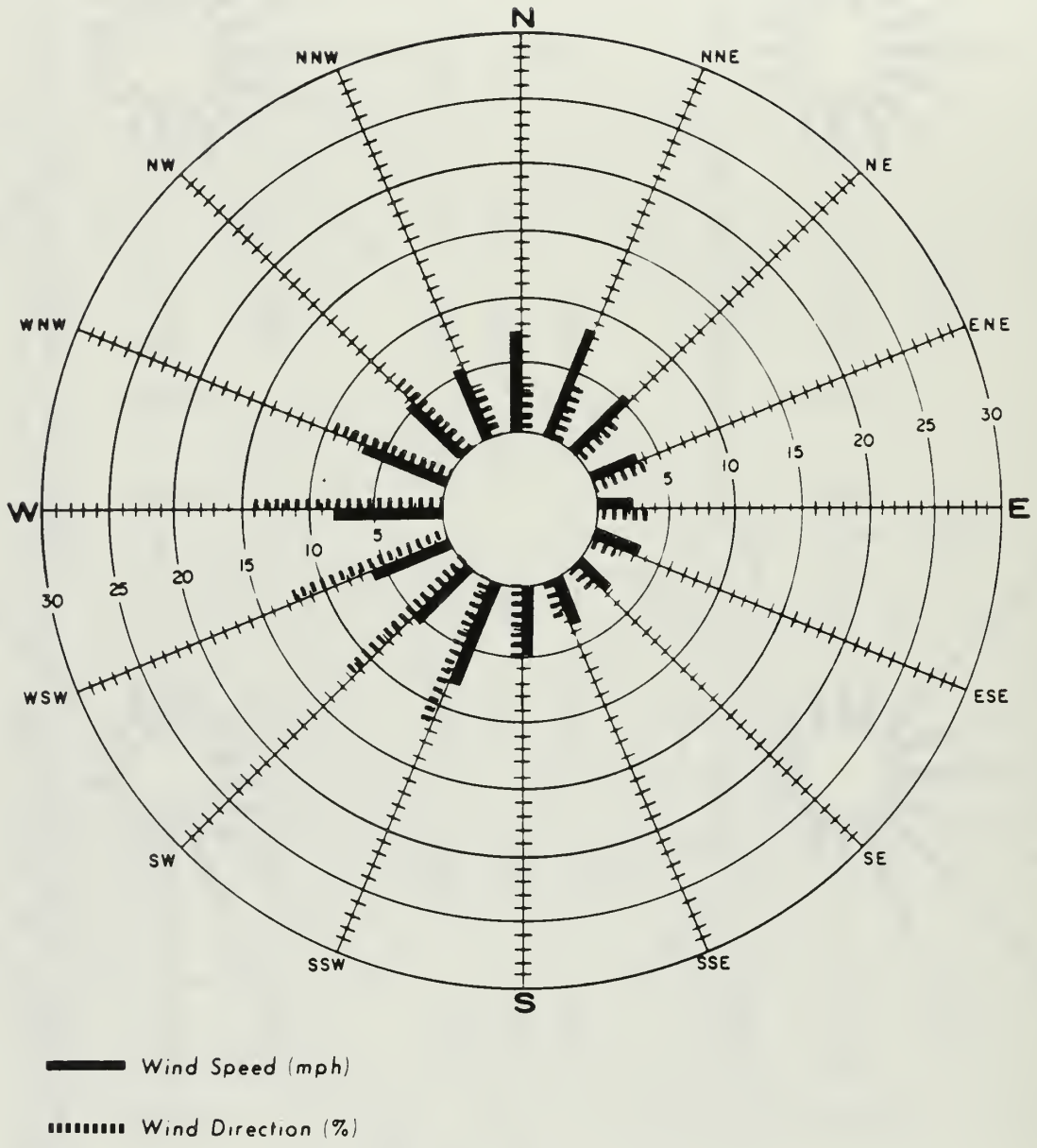

Figure 2-3. Annual Wind-Rose, January-December 1984, Site 1 10-m Level, Tract C-a.

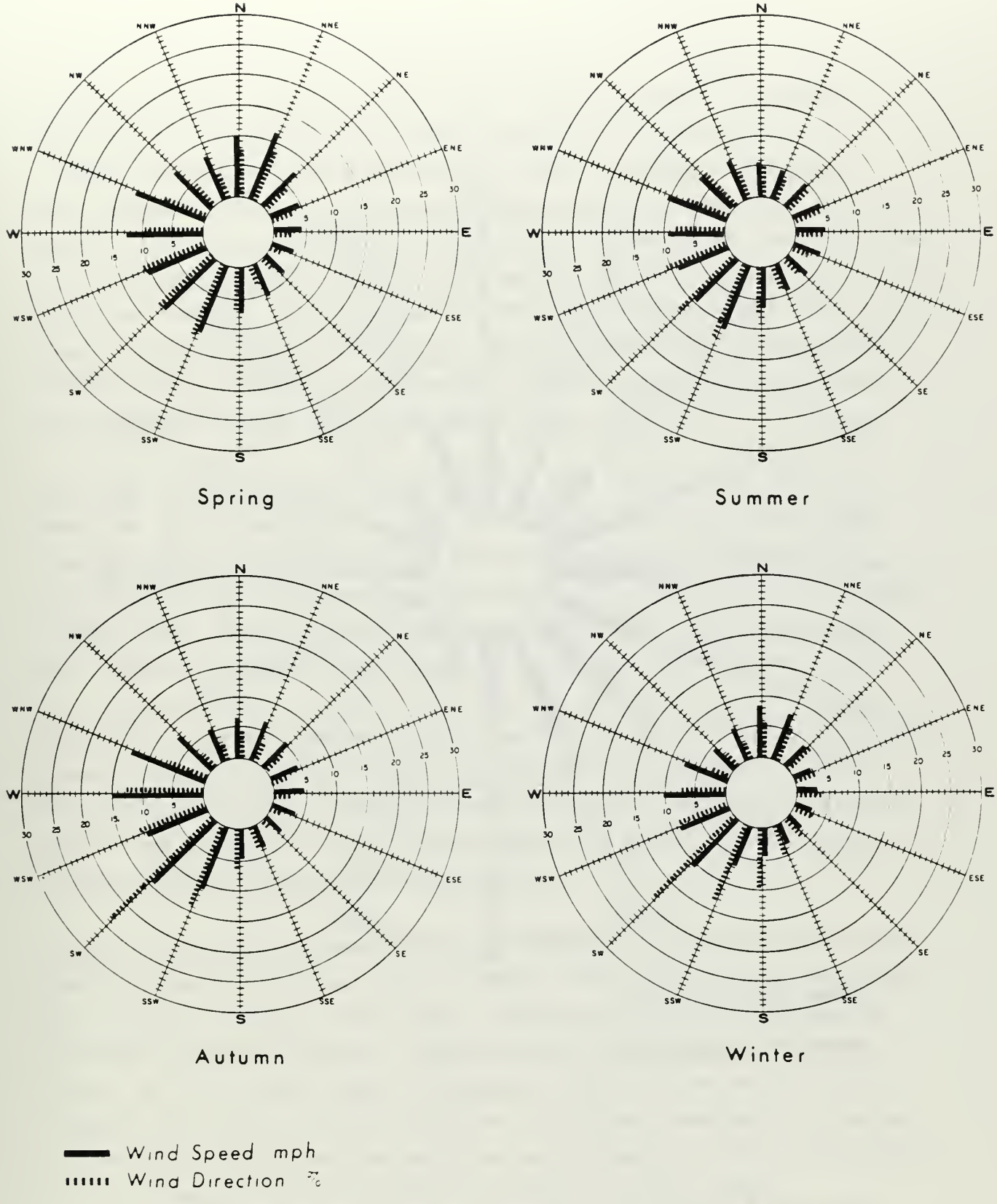

Figure 2-4. Seasonal Wind Roses, January-December 1984, Site 1, 60-m Level, Tract C-a.

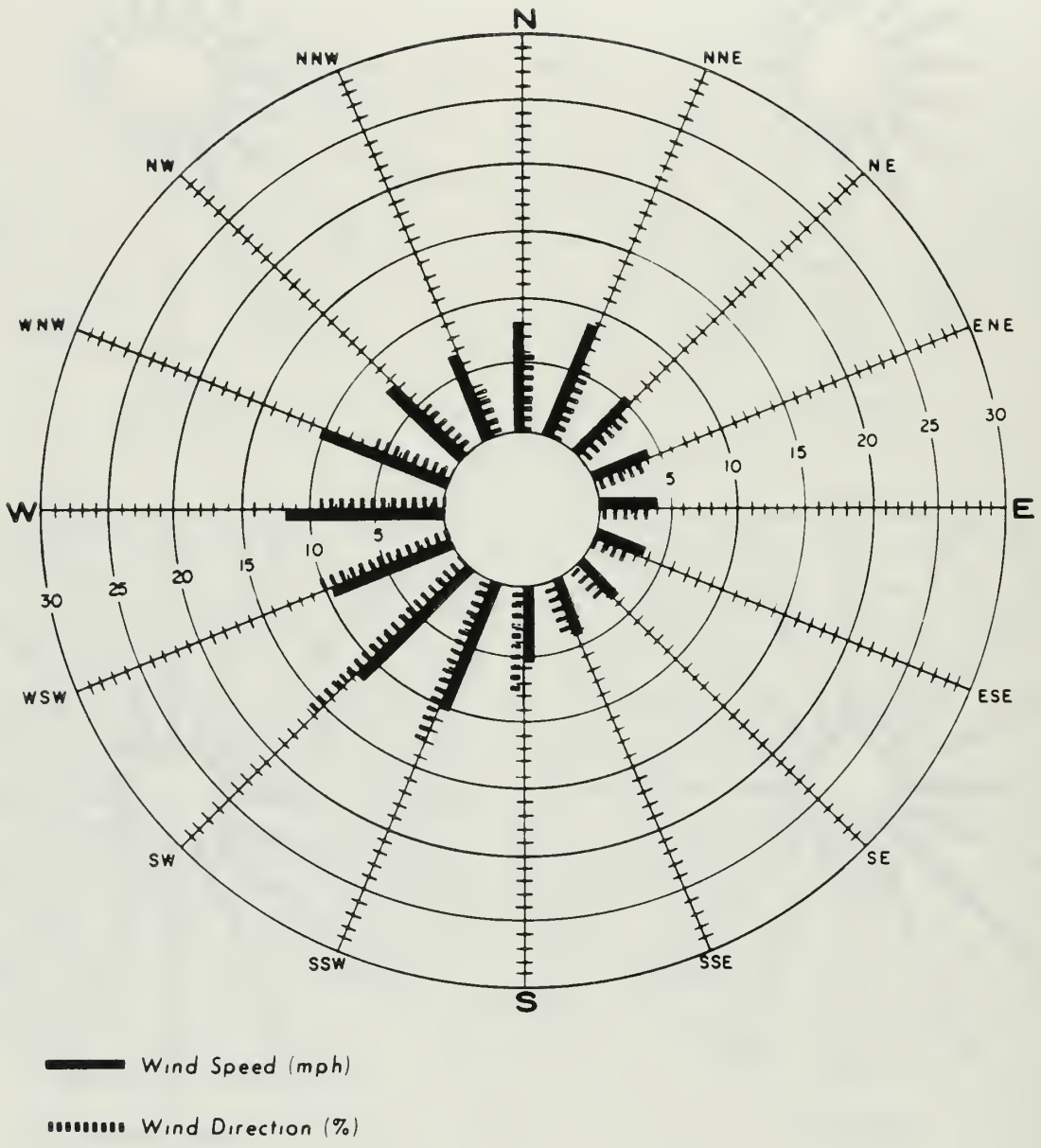

Figure 2-5. Annual Wind Rose, January-December 1984 Site 1 60-m Level, Tract C-a.

The Site 1 annual 10-m level wind rose for 1983 (Figure 2-3) shows the prevalent wind direction to be from the west (W on wind rose), with secondary maxima from the south-southwest (SSW), southwest (SW), and west-southwest (WSW). The mean wind speeds associated with these directions were 8.2, 8.0, 5.6 and 6.2 mph, respectively. The wind came from these four directions 50 percent of the time. These data compare well with annual wind roses for previous years at this site, which show the prevalent winds to be from the same directions. At Site 1, the wind directions with the lowest frequency of occurrence, as well as the lowest average wind speeds, were in the southeast quadrant during the entire data record.

The Site 1 annual 60-m level wind rose for 1984 (Figure 2-5) shows the prevalent wind direction to be from the southwest, with secondary maxima from the west, west-southwest, and the south-southwest. The mean wind speeds associated with these directions were 11.7, 11.9, 9.6, and 10.1 mph, respectively. These data are similar to data from previous years, which also show the prevalent wind directions to be from the southwest.

Table 2-13 contains a summary of the absolute maximum and mean hourly wind speed recorded at the two sites during each of the data years. The mean wind speeds during the current year were 6.3 mph at the Site 1 10-m level and 8.6 mph at the Site 1 60-m level. Mean wind speeds during 1984 were slightly lower than during previous years.

Tables 2-14 and 2-15 present the annual frequency of wind direction occurrences by hour for the two levels at Site 1 during 1984. These tables show the same data as given in the annual wind roses, but also illustrate the variation throughout the day. Each site shows the dominance of westerly winds. At Site 1 10-m level, for example, the wind blows from the five westerly 22.5^{o} sectors (south-southwest through west-northwest) 60 percent of the time averaged over the day. The only exception to this in the early morning, when an upslope (easterly) wind flow is fairly common.

Table 2-13. Summary of Annual and Mean Wind Speeds (mph) During the Baseline and MDP Periods, Tract C-a.

Wind Speeds (mph)[1/]	2/75-1/76	2/76-1/77	1978	1979	1980	1981	1982	1983	1984	Combined 9-Year Data Set
Site 1 (10-m level)										
Maximum	30.8	32.3	27.2	28.7	31.6	26.1	29.6	31.0	38.4	38.4
Mean	7.7	7.2	7.3	7.3	7.3	7.0	6.9	6.6	6.3	7.1
Site 1 (60-m level)										
Maximum	43.0	56.6	41.5	38.0	40.8	33.8	37.8	40.5	38.4	56.6
Mean	10.6	10.0	10.2	9.5	10.1	9.7	9.4	8.9	8.6	9.7

1/ Values based on hourly averages.

TABLE 2-14 . WIND DIRECTION FREQUENCY (%) BY HOUR OF DAY, JANUARY TO DECEMBER 1984, 10 METER TOWER AT SITE 1, TRACT C-A

HOUR	WIND DIRECTION N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1	3.6	4.1	0.3	0.8	1.1	1.1	1.9	2.7	3.3	8.2	15.9	16.8	17.0	9.3	11.5	2.2
2	2.2	2.2	1.4	1.6	2.2	0.5	1.6	1.4	4.1	8.2	17.0	16.7	16.7	12.1	8.8	3.3
3	3.8	1.6	0.8	1.9	0.5	0.5	1.4	1.9	4.9	9.6	15.6	15.3	17.3	9.3	10.7	4.7
4	3.3	2.2	0.8	3.3	1.1	1.4	1.4	1.6	4.9	6.6	14.5	14.0	20.5	13.2	8.2	3.0
5	3.0	1.9	1.6	2.2	0.5	1.4	2.2	3.0	3.3	9.0	14.8	17.5	14.8	13.2	9.3	2.2
6	3.0	2.2	2.2	1.1	1.1	0.8	2.2	1.9	5.5	13.4	14.0	13.2	17.0	11.5	8.5	2.5
7	3.3	5.5	1.6	4.7	0.5	1.4	2.2	1.9	8.2	12.3	12.9	14.5	10.4	8.8	5.8	6.0
8	4.4	3.6	4.4	10.1	6.3	2.5	3.3	6.6	6.3	9.6	11.8	8.8	11.8	4.4	4.1	2.2
9	3.0	4.9	5.5	9.6	9.9	3.3	3.8	4.1	10.2	10.7	7.1	6.0	13.5	3.0	3.0	2.2
10	2.7	4.7	5.2	7.4	12.9	5.2	3.6	3.3	7.7	9.9	9.0	6.8	13.4	3.0	3.3	1.9
11	3.0	5.5	5.2	10.4	7.9	3.3	2.2	3.6	6.6	14.0	7.9	7.4	14.0	3.3	3.8	1.9
12	3.3	6.6	4.9	7.7	5.2	4.1	1.9	1.6	6.0	13.4	9.0	10.1	12.1	6.6	3.8	3.6
13	5.0	5.2	6.9	7.7	4.1	1.9	2.2	1.1	5.5	13.2	10.5	9.9	12.4	6.6	3.3	4.4
14	5.0	5.0	6.6	4.4	5.8	1.4	1.4	1.9	4.4	16.1	9.1	10.5	10.8	9.4	3.9	4.2
15	6.0	5.2	5.2	4.4	4.9	1.9	1.1	1.9	4.4	18.1	10.4	9.1	8.2	9.3	6.3	3.3
16	5.2	3.8	6.6	4.1	5.2	1.1	1.9	1.4	5.5	17.9	8.2	8.8	9.1	8.5	7.7	4.9
17	4.9	4.7	3.0	3.8	4.4	2.7	1.6	2.5	7.1	15.7	11.3	6.9	9.1	8.2	7.7	6.3
18	2.5	6.3	2.8	1.7	1.9	2.2	1.4	4.1	2.5	17.4	11.0	6.1	12.4	11.0	9.4	7.4
19	4.4	5.2	2.5	1.1	2.2	1.4	1.9	1.9	2.7	11.0	14.3	10.7	14.8	11.3	10.4	4.1
20	2.2	5.5	1.9	1.1	0.8	1.1	0.8	1.7	3.9	8.8	10.2	17.9	14.9	16.3	8.8	4.1
21	2.5	4.7	2.2	0.6	0.8	1.1	0.8	0.8	4.4	8.0	13.2	18.5	17.1	12.7	9.1	3.6
22	3.3	3.0	3.8	0.5	0.5	1.1	1.4	2.2	3.0	7.7	16.2	16.2	16.8	12.6	7.1	4.4
23	3.0	3.3	1.9	0.8	2.2	0.5	0.8	2.2	3.8	5.5	18.1	17.6	16.5	9.6	7.4	5.6
24	2.5	3.3	1.4	1.4	0.3	0.8	1.1	2.7	3.0	6.3	16.7	18.4	16.2	11.8	10.4	3.8
MEAN	3.5	3.5	3.5	3.5	3.4	1.8	1.8	2.4	5.1	11.3	12.5	12.4	14.0	9.4	7.2	3.9

TABLE 2-15. WIND DIRECTION FREQUENCY (%) BY HOUR OF DAY, JANUARY TO DECEMBER 1984 60 METER TOWER AT SITE 1, TRACT C-A

HOUR	WIND DIRECTION															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1	8.1	5.7	4.5	2.1	1.5	0.9	2.1	4.8	9.3	13.8	14.1	9.6	10.2	6.9	3.9	2.4
2	7.8	4.5	5.1	2.1	1.2	2.7	2.7	3.6	9.9	11.7	15.3	11.1	8.7	6.6	3.6	3.3
3	9.0	6.6	4.5	0.9	1.5	2.4	1.8	5.4	7.8	13.8	12.9	10.2	9.9	5.4	3.3	4.5
4	10.5	4.5	4.5	1.8	1.2	1.5	3.6	3.6	8.1	12.0	13.5	10.5	12.3	4.8	3.3	4.2
5	8.4	6.0	3.0	2.1	2.1	1.5	3.6	5.1	9.0	11.1	15.9	12.0	10.2	3.6	3.0	3.3
6	6.3	5.7	3.9	1.2	3.0	1.5	3.0	3.9	10.2	12.3	13.8	11.4	9.9	5.1	5.4	3.3
7	6.0	5.4	3.3	2.4	1.8	1.2	1.8	5.1	8.7	15.9	13.5	12.6	9.3	4.8	4.2	3.9
8	4.5	3.9	6.3	6.6	4.5	3.6	3.6	6.6	9.9	11.4	12.6	10.2	8.1	3.9	2.7	1.5
9	4.8	3.9	6.6	10.2	5.7	4.8	3.6	4.2	9.3	11.4	12.3	11.4	7.8	1.8	1.2	0.9
10	3.0	4.2	5.1	9.6	7.2	3.9	4.5	2.7	9.9	11.1	15.0	11.4	7.2	1.5	1.5	2.1
11	3.3	4.8	4.2	6.0	6.9	2.7	3.6	4.2	6.3	12.6	16.8	13.8	7.5	2.1	3.3	1.8
12	3.6	5.4	4.5	4.2	3.6	3.3	2.7	3.0	6.0	11.4	16.8	14.1	9.9	5.4	1.8	4.2
13	3.6	3.9	4.5	4.8	5.4	2.4	1.5	2.4	3.9	12.7	18.7	14.2	7.9	5.4	5.1	3.3
14	4.8	4.2	5.2	1.8	5.8	2.7	0.6	2.4	5.2	13.0	18.5	11.5	10.6	6.4	4.2	3.0
15	5.2	4.8	3.0	3.6	5.5	2.1	1.2	2.4	3.9	15.8	20.0	7.9	8.2	7.3	6.1	3.0
16	3.6	3.3	5.4	3.3	5.1	2.1	1.5	1.5	4.5	15.4	16.6	6.9	12.0	7.5	6.6	4.5
17	3.9	3.6	3.9	3.9	3.9	2.1	2.7	1.8	5.7	13.9	16.3	7.5	10.2	10.2	6.0	4.2
18	4.8	5.1	2.1	3.0	2.1	1.2	1.8	4.5	4.5	15.4	14.8	6.0	9.1	12.1	8.5	4.8
19	6.0	6.3	3.9	1.5	2.7	1.2	1.5	4.2	6.0	13.6	16.9	6.0	6.9	11.4	7.5	4.2
20	6.0	7.9	3.9	2.1	0.9	1.8	1.8	4.2	7.6	12.7	17.5	6.0	6.9	8.2	8.2	4.2
21	4.8	7.9	2.7	3.3	1.2	0.6	2.1	3.0	8.2	15.7	16.0	7.3	8.8	7.6	6.0	4.8
22	7.8	5.4	5.1	1.5	0.9	2.1	2.4	4.2	10.2	11.7	17.2	7.5	8.1	6.6	4.8	4.2
23	6.0	6.6	3.0	1.5	1.8	1.5	2.1	3.9	9.6	11.7	17.2	11.7	8.4	6.6	3.9	4.2
24	6.3	6.9	3.3	1.5	1.8	1.2	2.4	3.6	8.1	11.7	17.1	10.8	9.9	4.8	3.9	6.6
MEAN	5.8	5.8	5.8	5.8	3.2	2.1	2.4	3.8	7.6	13.0	15.8	10.1	9.1	6.1	4.5	3.6

This morning upslope flow (caused by local solar heating of the terrain) can be shown by comparing the relative frequency of easterly and southeasterly winds (which are relatively uncommon) at the 10-m level. During midafternoon, winds from the five 22.5° sectors east northeast through south southeast occur approximately 14 percent of the time, and are present an average of only 6 percent of the time during the middle of the night. However, these winds occur 32 percent of the time at 0900 and 1000 hours, during the peak period of the upslope flow. The predominance of the westerly winds and the morning upslope flow are the major features of the surface wind regime.

One method for determining atmospheric stability involves measures of wind turbulence. Tables 2-16 and 2-17 present stability classes based upon the standard deviation of the horizontal wind direction fluctuations (σ_Θ), at the 10 and 60-m levels at Site 1, respectively. The stability classes range from "A" (extremely unstable) to "G" (extremely stable). Calculations of stability class is based upon recommendations by the Air Pollution Control Division of the Colorado Department of Health (1983). The most common stability class is "D" (Neutral), which occurred 33 percent of the time.

C. Precipitation

1. Objectives

Precipitation is recorded to provide data on the moisture availability for plant growth and revegetation.

2. Methods

The methods followed for collection of these data were described in MDP Report 2 (RBOSC 1978).

Table 2-16. Monthly, Seasonal, and Annual Occurrence (hours) of Stability Classes Based Upon the Site 1 10-m Horizontal Wind Direction Fluctuation (σ_Θ), 1984, Tract C-a

Period	Stability Classes							Total
	A	B	C	D	E	F	G	
January	63	54	62	212	189	89	75	744
February	38	28	82	219	199	34	71	671
March	38	52	77	299	219	31	27	743
April	50	69	121	275	152	27	24	718
May	94	97	139	218	142	33	21	744
June	95	110	133	192	129	32	28	719
July	156	84	95	189	159	32	16	731
August	126	92	92	212	163	33	25	743
September	85	81	108	226	159	38	22	719
October	55	66	104	290	172	34	23	744
November	42	62	96	269	155	43	53	720
December	45	57	96	290	142	47	67	744
Winter	146	139	240	721	530	170	213	2159
Spring	182	218	337	792	513	91	72	2205
Summer	377	286	320	593	451	97	69	2193
Fall	182	209	308	785	486	115	98	2183
Annual	887	852	1205	2891	1980	473	452	8740

Table 2-17. Monthly, Seasonal, and Annual Occurrence (hours) of Stability Classes Based Upon the Site 1 60-m Horizontal Wind Direction Fluctuation (σ_Θ), 1984, Tract C-a

	Stability Classes							
Period	A	B	C	D	E	F	G	Total
January	20	20	67	278	269	53	37	744
February	21	19	52	274	231	43	52	692
March	27	29	69	264	304	27	23	743
April	30	25	77	301	247	21	18	719
May	50	48	127	284	160	34	41	744
June	56	56	116	253	179	33	26	719
July	99	68	92	233	183	35	21	731
August	79	65	111	224	195	42	27	743
September	23	35	85	170	134	20	25	492
October	3	6	26	99	37	5	6	182
November	18	28	77	303	209	43	42	720
December	28	41	76	359	171	36	33	744
Winter	69	80	195	911	671	132	122	2180
Spring	107	102	273	849	711	82	82	2206
Summer	234	189	319	710	557	110	74	2193
Fall	44	69	188	572	380	68	73	1394
Annual	454	440	975	3042	2319	392	351	7973

3. Results and Discussion

Data from the three types of precipitation gauges for 1984 are included in Appendix 2-2.2. Snow depth measurements taken during 1984 are presented in Appendix 2-2.3.

Table 2-18 presents the monthly, seasonal, and annual precipitation at Site 1 for 1984. The table is compiled from data which are collected by tipping bucket, weighing bucket, and wedge gauges. Precipitation measured by the three gauges during 1984 ranged from 19.60 to 22.14 inches. Although the natural variability of precipitation is high in semi-arid regions, a substantial part of the range in values is probably due to different exposures and capture efficiencies of the gauges.

The weighing bucket gauges are thought to produce the most representative precipitation data, due to a better exposure and the improvement in winter capture efficiency through the use of snow shields. The tipping bucket gauges have historically recorded lower amounts of precipitation than other gauges, which may be due to a less efficient capture and measurement technique (RBOSC 1980).

Table 2-19 presents the results of the precipitation measurements collected onsite over the past seven years. The table shows that 1984 was the wettest year during the entire period of record. The best estimate of annual precipitation, based on data from the weighing bucket gauges, indicates that precipitation totalled approximately 14 inches in 1978 and 1979, 12 inches in 1980, 17 inches in 1981, 16 inches in 1982, 21 inches in 1983 and 22 inches in 1984.

The wettest month during 1984 was July with 3.75 inches, followed closely by August (3.45 inches), September (3.34 inches), and April 2.93 inches). The precipitation falling during these four months represents 61 percent of the total 1984 precipitation. Based upon the precipitation record measured at Tract C-a, it is highly unusual to have several months with relatively high

Table 2-18. Monthly, Seasonal, and Annual Precipitation (inches) at Site 1 from Available Tipping Bucket Gauge, Weighing Bucket Gauge, and Wedge Gauge Data at Tract C-a for the period January - December 1984.

Month	Site 1		
	Tipping Bucket Gauge	Weighing Bucket Gauge	Wedge Gauge
January	0.23	0.44	0.46
February	0.56	0.71	0.50
March	1.59	1.81	1.41
April	2.39	2.93	2.45
May	0.93	0.89	1.02
June	3.64	3.75	3.65
July	1.08	1.06	1.04
August	3.45	3.62	3.00
September	3.34	3.25	2.78
October	2.21	2.31	2.35
November	0.12	0.40	0.45
December	0.06	0.97	0.97
Seasonal			
Winter (Dec, Jan, Feb)	0.85	2.12	1.93
Spring (Mar, Apr, May)	4.91	5.63	4.88
Summer (Jun, July, Aug)	8.17	8.43	7.69
Fall (Sep, Oct, Nov)	5.67	5.96	5.58
Annual	19.60	22.14	20.08

Table 2-19. Summary of Precipitation Measurements (inches) During the Past Seven Years at Site 1 at Tract C-a.

Gauge	1978	1979	1980	1981	1982	1983	1984
Tipping Bucket							
Winter	--	0.81	1.86	0.75	1.02	2.05	0.85
Spring	--	3.66	3.83	3.34	2.00	6.60	4.91
Summer	--	2.38	2.65	4.29	2.55	2.77	8.17
Fall	1.63	2.93	0.98	4.87	--	4.40	5.67
Annual	--	9.78	9.32	13.25	--	15.82	19.60
Weighing Bucket							
Winter	4.15	2.24	2.27	1.92	2.59	3.32	2.12
Spring	5.15	6.06	5.25	3.61	3.05	8.95	5.63
Summer	1.71[1/]	2.17	2.56	4.69	3.08	3.04	8.43
Fall	3.21	3.28	1.52	6.59	7.64	5.65	5.96
Annual	14.22	13.75	11.60	16.81	16.36	20.96	22.14
Wedge							
Winter	3.28	1.50	2.52	1.85	2.25	3.37	1.93
Spring	4.27	5.44	4.99	4.91	3.01	7.09	4.88
Summer	1.82	2.28	3.25	5.14	3.23	3.37	7.69
Fall	2.94	2.15	2.24	5.73	7.80	5.09	5.58
Annual	12.31	11.65	13.14	18.34	16.28	18.92	20.08

precipitation. During the previous six years, no more than one month in each year had more than 3 inches of precipitation. Apparently, the increased precipitation was due to a greater number of storms bringing more precipitation over a considerable part of the year, rather than a few events increasing precipitation over a short period of time.

D. Solar Radiation

1. Objective

Solar radiation is monitored to supplement the data base for interpreting the meteorological and air quality data.

2. Methods

The methods followed for collection of these data were described in MDP Monitoring Report 4 (RBOSC 1979b).

3. Results and Discussion

Table 2-20 presents the maximum and mean (based on daylight hours only) monthly solar radiation at Site 1 for 1984. The average solar radiation during daylight hours was calculated to be 0.53 ly/min.

Table 2-20. Maximum and Mean Solar Radiation (ly/min) at Site 1, January-December 1984, RBOSC Tract C-a

Month	Maximum[1/] Solar Radiation (ly/min)	Mean[1/] Solar Radiation (ly/min)
January	0.86	0.41
February	1.05	0.43
March	1.38	0.49
April	1.36	0.59
May	1.41	0.69
June	1.48	0.65
July	1.46	0.66
August	1.36	0.61
September	1.29	0.58
October	1.10	0.37
November	0.85	0.36
December	0.80	0.29
Season		
Winter	1.05	0.38
Spring	1.41	0.59
Summer	1.48	0.64
Fall	1.29	0.44
Annual	1.48	0.53

1/ Maximum and mean values computed from hourly average during daylight hours.

2.3 CLIMATOLOGY

This section presents a description of the general climatology of the region in which Tract C-a is located.

1. Objectives

It is the intent to develop a climatology by comparing meteorological data collected from the RBOSC site (defined as "onsite") with both short-term and long-term climatic data available from other meteorological stations in the region. The rugged topography of western Colorado causes variations in climate within short distances, and caution must be used when applying climatic generalizations to the whole area. Ideally, the most accurate way of characterizing the climatology of Tract C-a is to develop a long-term meteorological data base from data gathered onsite. The available onsite meteorological data base of nine years cannot be construed as being representative of the long-term climatic conditions in the tract area; however, the onsite data can be compared with similar short-term and long-term data in the region to identify site-specific climatic conditions due to elevation, exposure, and the orientation of mountain ranges and valleys.

2. Methods

The methods followed for collection of climatological data were described in MDP Monitoring Report 3 (RBOSC 1979a).

3. Results and Discussion

Figure 2-6 presents the sources of climatological data in the northwest section of the State of Colorado, where Tract C-a is located at an average elevation of 7000 feet above Mean Sea Level. The weather station closest to the tract is Little Hills, located 15 miles to the northeast at an elevation of 6140 feet. The Meeker No. 2 station is located about 30 miles to the east-northeast at an elevation of 6350 feet. Grand Junction, at an

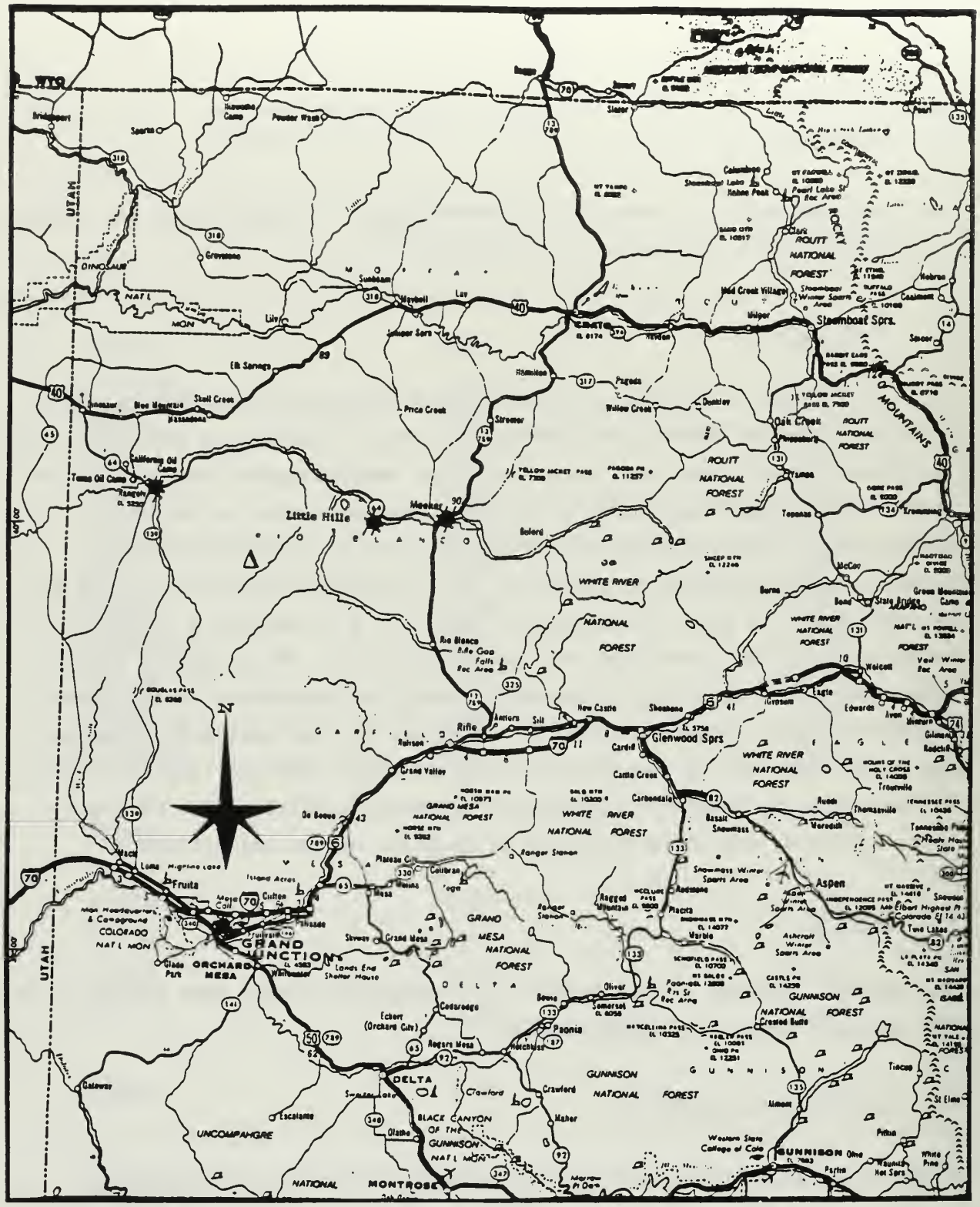

Figure 2-6. Map of Northwest Colorado Showing the Rio Blanco Region.

elevation of 4843 feet, is about 60 miles south of the site. All of these stations monitor temperature and precipitation. At Grand Junction other parameters are measured as well. A discussion of the climatology and the influences of topography on the general meteorological and climatic conditions in the area was presented in the Final Environmental Baseline Report (RBOSP 1977).

Meteorological data collected at the site during 1984 can be compared to data for the same period from Grand Junction and to the Grand Junction long-term average for the period 1951-1980. Table 2-21 presents the monthly departures from normal for Grand Junction mean temperature and total precipitation during the current year. The departure of the 1984 mean annual temperature at Grand Junction from the long term average was -0.3 ^{o}F. The Grand Junction mean annual temperature exceeded the RBOSC Site 1 mean during 1984 by 9.8^{o}F. The annual precipitation during the current year at Grand Junction was 11.59 inches, nearly 50 percent above the long-term average. This was still 10.55 inches below the total measured at Site 1 for the year.

Table 2-21 indicates that Grand Junction data compares rather poorly with onsite data. The mean annual temperature at Grand Junction has been consistently 7-10 ^{o}F higher than the mean at Tract C-a during the last eight years. In addition, total annual precipitation has been higher at Tract C-a than at Grand Junction in each of the last six years, ranging from 1.7 to 10.55 inches higher. Consequently, Grand Junction data should be used very cautiously in describing the climatology of the region. This climatic difference between Site 1 and Grand Junction can also be seen in the frost-free period (Table 2-11), which has averaged 50 days longer at Grand Junction over the last four years.

This difference is not unexpected, since Grand Junction is located in a valley approximately 2500 feet lower than Site 1. In fact, by using the NACA Standard Atmosphere lapse rate for 40^{o}N latitude of 3.57 F/1000 ft (Hess 1959), an estimate can be made of the temperature that would be expected if the Grand Junction station was at the same altitude as Site 1.

Table 2-21. Monthly Departures from the Long-Term Means for the Data Period January-December 1984 for Grand Junction and Comparison with Tract C-a Annual Values.

Month	Temperature (°F) Long Term Mean	1984 Mean	Departure from Mean	Precipitation (inches) Long Term Mean	1984 Total	Departure from Mean
Grand Junction						
January	25.5	20.7	-4.8	0.64	0.28	-0.36
February	33.5	31.7	-1.8	0.54	0.11	-0.43
March	41.9	44.4	+2.5	0.75	1.57	+0.82
April	51.7	49.0	-2.7	0.71	1.21	+0.50
May	62.1	66.2	+4.1	0.76	0.55	-0.21
June	72.3	70.1	-2.2	0.44	1.68	+1.24
July	78.9	78.0	-0.9	0.47	0.62	+0.15
August	75.9	76.6	+0.7	0.91	1.77	+0.86
September	67.1	68.3	+1.2	0.70	0.34	-0.36
October	54.9	50.2	-4.7	0.87	2.65	+1.78
November	39.6	40.8	+1.2	0.63	0.38	-0.25
December	29.5	32.8	+4.3	0.55	0.43	-0.12
Annual	52.7	52.4	-0.3	7.97	11.59	+3.62
RBOSC Site 1		42.6			22.14	
RBOSC departure from Grand Junction		-9.8			+10.55	
RBOSC Site 1 Means	44.2 1/			16.55 2/		

1/ Based on 9-year data record

2/ Based on 7-year data record

Using this approximation, the Grand Junction mean annual temperature would be reduced by 8.9°F. Thus, the large discrepancy in mean annual temperatures between the site and Grand Junction can be accounted for largely by the altitude differential.

Table 2-22 presents monthly temperature data collected during 1984 from Site 1, two nearby climatological stations (Meeker No. 2, and Little Hills), and Grand Junction. The table shows, as discussed above, that Grand Junction temperature data are not very representative of temperatures of Rio Blanco County. The mean monthly and annual temperatures at the two climatological stations in the county agree fairly well with the onsite data, especially considering the elevation and topographical differences among the sites. However, a major difference between Site 1 and the other stations is evident in the temperature range (the difference between the maximum and the minimum), which is greater at the climatological stations. This is due primarily to the relative height of the instruments above the ground surface. Climatological stations measure temperature 6 feet above the ground in a standard weather shelter, whereas the Site 1 temperature sensor is located at 10 meters (33 ft.). Since temperature changes in the lower layers of the atmosphere result from heat transfer to and from the ground surface, the diurnal temperature range will decrease with height above the ground. Thus, the reduced temperature range at Site 1 relative to the surrounding stations is largely due to the increased height above ground of the temperature sensors at Site 1.

Table 2-23 presents a comparison of precipitation data from Site 1 and from surrounding stations for the current year. Monthly precipitation amounts at all of the stations vary widely due to the complex orographic influences of the region and the intermittent nature of precipitation (particularly during the summer). Annual totals between Site 1 and the climatological stations range between 16 and 22 inches. Grand Junction, with 12 inches of precipitation, had the lowest monthly total of all stations, probably because of its location in a large valley.

Table 2-22. Comparison of Monthly Temperatures (^{o}F) in the Vicinity of Tract C-a for the Data Period January-December 1984.

	Tract C-a Site 1			Little Hills			Meeker No. 2			Grand Junction		
Month	Avg Max	Avg Min	Mean	Avg Max	Avg Min	Mean	Avg Max	Avg Min	Mean	Avg Max	Avg Min	Mean
January	27.5	15.8	21.7	26.6	-9.8	8.4	28.9	-0.6	14.2	31.9	9.4	20.7
February	31.6	19.2	25.0	35.1	-0.8	17.2	37.7	7.9	22.8	41.9	21.4	31.7
March	36.1	23.2	29.7	40.5	14.4	27.5	44.5	20.0	32.3	54.9	33.9	44.4
April	43.3	28.8	36.0	49.3	20.6	35.0	52.5	25.0	38.8	61.5	36.5	49.0
May	71.4	45.0	54.1	68.7	31.2	50.0	72.1	37.6	54.9	80.7	51.7	66.2
June	66.0	49.6	57.9	71.1	36.3	53.7	74.7	42.1	58.4	83.6	56.5	70.1
July	75.6	58.8	67.3	81.1	44.8	63.0	85.0	51.2	68.1	92.3	63.6	78.0
August	73.0	58.5	65.7	80.5	46.7	63.6	82.1	49.6	65.9	88.4	62.2	76.6
September	65.1	48.6	56.7	73.1	37.1	55.1	74.6	39.8	57.2	81.3	55.2	68.2
October	45.1	32.9	38.7	53.7	26.7	40.2	54.7	30.3	42.5	59.7	40.7	50.2
November	40.3	27.9	34.0	49.7	14.8	32.3	48.5	19.8	34.2	51.9	29.7	40.8
December	31.1	19.9	25.5	36.7	12.0	24.4	36.7	12.0	24.4	40.1	25.1	32.6
Annual			42.6			39.2			42.8			52.4

Table 2-23. Comparison of Monthly Precipitation (inches) in the Vicinity of Tract C-a for the Data Period January-December 1984.

Month	Tract C-a Site 1	Little Hills	Meeker No. 2	Grand Junction
January	0.44	0.46	0.37	0.28
February	0.71	0.63	0.16	0.11
March	1.81	2.09	1.62	1.57
April	2.93	2.84	2.24	1.21
May	0.89	0.48	1.01	0.55
June	3.75	2.84	3.71	1.68
July	1.06	0.60	0.73	0.62
August	3.62	3.00	1.33	1.77
September	3.25	1.78	1.03	0.34
October	2.31	2.31	2.26	2.65
November	0.40	0.71	0.61	0.38
December	0.97	0.58	0.68	0.43
Annual	22.14	18.32	15.75	11.59

2.4 QUALITY ASSURANCE AND DATA RECOVERY

The data upon which this report is based, with the exception of the visibility, precipitation and total suspended particulate data, were collected by an automatic data acquisition system located on Tract C-a. The data are recorded on magnetic tape, paper printouts and analog strip chart recorders. A comprehensive quality assurance program has been maintained to ensure the reliability and accuracy of the data. This program includes documentation by the site technician of all calibrations and system malfunctions, weekly zero and span calibrations of the air quality instrumentation, utilization of control charts onsite to detect problems in the weekly span calibrations, quarterly calibrations of the air quality instrumentation by both the RBOSC technical staff and an independent auditing team, semiannual calibrations of the meteorological instrumentation, and review of the analog and digital data by qualified analysts.

The air quality instruments are calibrated with reference gases traceable to National Bureau of Standards (NBS) standards. The carbon monoxide, sulfur dioxide, hydrogen sulfide, and nitrogen oxide analyzers were calibrated using known concentrations of test gases which had been certified by the vendor. The ozone analyzer is calibrated using a U.V. photometer.

Each instrument was tested at least once a week by inserting a zero pollutant concentration and at least one upscale concentration. These tests provided data on instrument drift and ensured that the instrument would respond to a detectable level of pollutant concentration in the ambient air.

The quarterly field calibrations were used to determine the accuracy of the instruments. Independent air quality quarterly audits were performed by a contractor (Northrop, Inc.) in February and May of 1984 (the air quality monitoring program was shut down on July 1, 1984). Internal audits by RBOSC staff of the TSP monitors were made in September and December of 1984.

The air quality data include many values representing hours when the concentration of some pollutants fell below the reliable threshold of detection of the instrument (based on the manufacturer's specifications). When this occurred, a number equal to one-half the threshold value was substituted for the data point. This procedure is adopted from the EPA Quality Assurance Handbook, Air Pollution Measurement, Vol. 1. This applied to sulfur dioxide, hydrogen sulfide, nitrogen oxides, and carbon monoxide data acquired through much of the data period.

The meteorological system is calibrated on a semiannual basis. This includes routine replacement of all wind speed and wind direction sensors. No correction factors were required to adjust the data.

Data recoveries for all meteorological and air quality parameters collected by the onsite data acquisition system are presented in Tables 2-24 and 2-25. The data recovery for all parameters exceeded 90 percent.

Table 2-24. Annual Data Recovery (%) of Meteorological Parameters Monitored at Tract C-a for the Period January-December 1984.

Parameter	Data Recovery (%)
Site 1	
10 m wind speed	99.5
10 m wind direction	99.5
60 m wind speed	91
60 m wind direction	91
10 m temperature	99
60 m temperature	99
Delta T 60-10 m	99
Solar radiation	99

Table 2-25. Annual Data Recovery (%) of Air Quality Parameters Monitored at Tract C-a for the Period January-June 1984.

Parameter	Data Recovery (%)
Site 1	
SO_2	97
H_2S	97
NO	99
NO_2	99
O_3	98
CO	99

2.5 VISIBILITY

Documentation of visibility in the Piceance Creek Basin is a cooperative study conducted by RBOSC and the Cathedral Bluffs Shale Oil Company.

1. Objectives

The objectives of this program are to document the visibility in the area of the Piceance Creek Basin and identify trends or variations in visibility which may be evident during the monitoring program. The results of this program will provide visibility data against which future data may be compared, and with which concurrent meteorological and air quality data may be incorporated for further evaluation and consideration.

2. Methods

Two methods have been used to measure visibility in the Piceance Basin: photography and telephotometry. During the Baseline Period (1975-76) and the first year of the MDP period (1978), only the photographic method was employed. This method was described in MDP Monitoring Report 1 (RBOSC 1978). From 1979 through 1982 visibility data were taken by both photographic and telephotometric methods; all results presented to date have been based on the photographic measurements. In April 1983, the Oil Shale Project Office approved elimination of the photographic measurements, provided that a consistent set of visibility data based on telephotometric measurements could be developed. All future results will be based upon telephotometric data. Data are normally collected every fourth day along four views from a centrally located shelter (Figure 2-7) during the spring and the fall.

Results

Table 2-26 presents a comparison of the telephotometric and photographic data collected from 1979-1982, when both monitoring techniques were used. The annual mean visual ranges, averaged over all views and all four years, were very close: 88 miles using the telephotometric data and 86 miles using

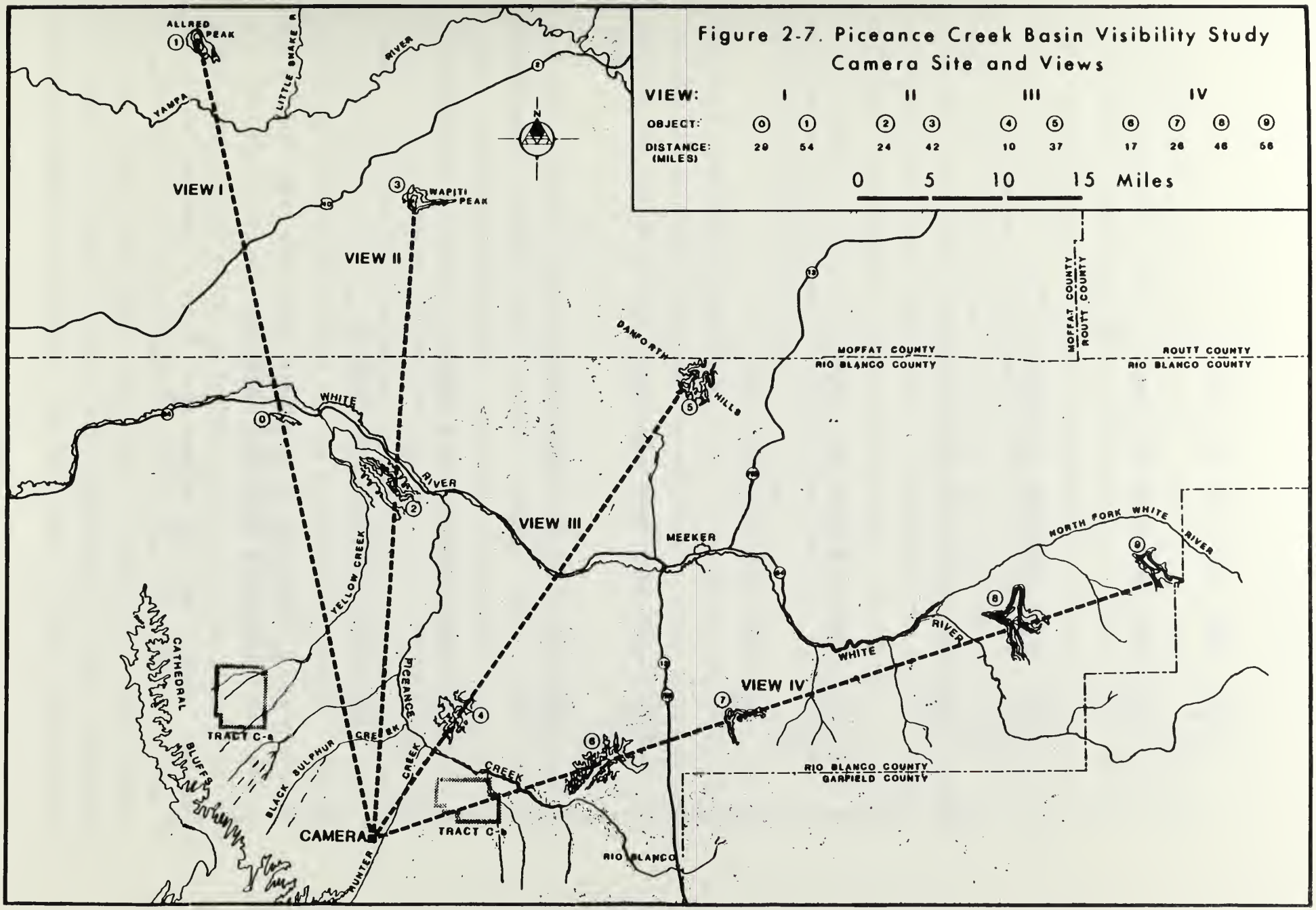
Figure 2-7. Piceance Creek Basin Visibility Study
Camera Site and Views
VIEW: I II III IV
OBJECT: 0 1 2 3 4 5 6 7 8 9
DISTANCE (MILES): 29 54 24 42 10 37 17 26 46 56
0 5 10 15 Miles
ALLRED PEAK
YAMPA
LITTLE SNAKE R
RIVER
WAPITI PEAK
VIEW I
VIEW II
VIEW III
VIEW IV
DANFORTH HILLS
MOFFAT COUNTY
ROUTT COUNTY
RIO BLANCO COUNTY
WHITE
RIVER
MEEKER
NORTH FORK WHITE
YELLOW CREEK
PICEANCE CREEK
CATHEDRAL BLUFFS
BLACK SULPHUR CREEK
TRACT C-a
TRACT C-b
CAMERA
HUNTER
RIO BLANCO
GARFIELD COUNTY

Table 2-26. Comparison of Visual Ranges (miles) Derived from Photographic and Telephotometric Data

		View I		View II		View III		View IV		All Views	
	Season	Photo-graphic	Telephoto-metric	Photo-graphic	Telephoto-metric	Photo-graphic	Telephoto-metric	Photo-graphic	Telephoto-metric	Photo-graphic	Telephoto-metric
1979	Spring	81	82	73	71	82	80	74	118	77	88
	Fall	84	99	76	80	82	96	94	132	84	102
	Annual	83	90	74	75	82	88	83	125	80	95
1980	Spring	80	80	72	67	76	78	85	106	78	83
	Fall	92	95	83	79	88	83	111	117	93	93
	Annual	85	88	77	73	82	80	97	111	85	88
1981	Spring	90	71	76	66	81	65	87	94	84	74
	Fall	88	82	82	73	87	83	92	102	87	85
	Annual	89	77	79	69	84	74	90	98	86	80
1982	Spring	111	79	109	75	107	80	114	108	109	86
	Fall	76	94	76	80	74	91	79	120	76	96
	Annual	93	86	92	77	91	86	96	114	93	91
1979-82	Spring	91	78	83	70	87	76	90	107	87	83
	Fall	85	93	79	78	83	88	94	118	85	94
	Annual	88	85	81	74	85	82	92	112	86	88

the photographic data. The spring mean visual range, using the telephotometric data averaged over all views, was four miles lower than the visual range derived from the photographic data (83 vs. 87 miles), while the fall mean visual range calculated from telephotometric data was 9 miles higher (94 vs. 85 miles). In order to develop a consistent set of visibility data, a set of "equivalent" telephotometric data were calculated for the first years (1975-76 and 1978) when only photographic data were collected. These "equivalent" data were calculated through the use of a regression equation developed from the data taken during the 1979-82 period, when both telephotometric and photographic data were available. The regression equation was then applied to the photographic data of 1975-76 and 1978. The regression analysis was done by Visibility Services, Inc. (1983) under contract to Cathedral Bluffs Shale Oil Company.

Table 2-27 presents the complete data set for the period 1975-1982. This includes the estimated "equivalent" telephotometric visual ranges derived by applying the regression equation to the photographic data for 1975-76 and 1978.

A review of the table shows that the visual ranges from the photographic and telephotometric methods agree very well, averaged over all seasons and all views. For 1975-76 through 1980, the visual ranges derived from the telephotometric method were slightly longer (averaging 6 miles farther), while the visual ranges derived from the photographic method were slightly longer in 1981 and 1982 (averaging 4 miles farther). The overall visual range averages for the two techniques are very close, 84 miles for the photographic method and 87 miles for the telephotometric method. However, the two techniques show large differences in some cases if the results for the individual views are considered: for Views I through III, the average annual visual range for the two methods differ by 3 miles or less; for View IV, the telephotometric visual range averages 14 miles farther. The average visual range for the telephotometric data in View IV is also much higher than any of the other average visual ranges. Review of the data indicate that one of the targets in View IV often gave spurious results, perhaps due to target shading. Consequently, the data appear to give a more representa-

Table 2-27. Comparison of Visual Ranges (miles) Derived from Photographic and Telephotometric Data

		View I		View II		View III		View IV		All Views	
	Season	Photo-graphic	Telephoto-metric	Photo-graphic	Telephoto-metric	Photo-graphic	Telephoto-metric	Photo-graphic	Telephoto-metric	Photo-graphic	Telephoto-metric
1975-76	Spring	74	78	63	70	67	82	73	81	69	78
	Fall	93	94	77	79	92	84	101	95	91	88
	Annual	83	86	69	74	78	83	85	88	79	83
1978	Spring	81	83	73	75	77	72	84	86	79	79
	Fall	87	94	76	77	71	78	86	97	80	87
	Annual	83	89	74	76	74	75	85	91	79	83
1979	Spring	81	82	73	71	82	80	74	118	77	88
	Fall	84	99	76	80	82	96	94	132	84	102
	Annual	83	90	74	75	82	88	83	125	80	95
1980	Spring	80	80	72	67	76	78	85	106	78	83
	Fall	92	95	83	79	88	83	111	117	93	93
	Annual	85	88	77	73	82	80	97	111	85	88
1981	Spring	90	71	76	66	81	65	87	94	84	74
	Fall	88	82	82	73	87	83	92	102	87	85
	Annual	89	77	79	69	84	74	90	98	86	80
1982	Spring	111	79	109	75	107	80	114	108	109	86
	Fall	76	94	76	80	74	91	79	120	76	96
	Annual	93	86	92	77	91	86	96	114	93	91
All Yrs.	Spring	86	79	78	71	82	76	86	99	83	81
	Fall	87	93	78	78	82	86	94	110	85	92
	Annual	86	86	78	74	82	81	89	105	84	87

Telephotometric Data for 1975 - 1976 and 1978 are estimated "equivalent" telephotometric values.

tive average visual range for the Piceance Basin if View IV is deleted. This conclusion was also made by the contractor conducting the regression analysis (Visibility Service Inc., 1983). If the data from View I through III are used to compute an average visual range in the Basin over the period of record, the photographic method gives an average of 82 miles while the telephotometric method averages 81 miles. No evidence of a trend in the visual range is apparent in the data from the Baseline Period to 1982. This is partially due to the difficulty in detecting a trend in data with a large variability.

Visual Ranges in 1983 and 1984

Modifications to the monitoring technique were made beginning in 1983 to improve the data quality. Contrast data were taken for all targets within a view rather than only at the most distant visible target. As a result, between two and four visual ranges for the same view could be computed, depending upon the number of targets within each view. Thus, obvious outliers could be discarded, improving the quality of the data set. In addition, the observer made a field estimate of visual range at each view, which was used as a check on data from the telephotometer.

The contrast threshold of the eye (C_m) used in the visual range calculation was set at 0.05 instead of the more typical 0.02. This value, according to a recent paper (Tombach and Allard, 1983), is more representative of what the public actually sees. Substitution of 0.05 in the calculation results in a visual range that is approximately 25 percent less than those obtained using the 0.02 C_m value. These visual ranges were substantially closer to the observer's estimated visual range, so the contrast ratio of 0.05 was used in calculating visual ranges from the telephotometer contrast data throughout the period of record, as presented earlier in Tables 2-26 and 2-27.

The daily mean visual ranges in 1983 are presented by view in Table 2-28 and Figure 2-8. Table 2-29 and Figure 2-9 present the same data for 1984. As the figures illustrate, the daily mean visual ranges for all views have a

Table 2-28. Daily and Seasonal Visual Ranges in Piceance Basin (miles) by View in 1983.

Date	View I	View II	View III	View IV	All Views
Spring					
05/04	83	70	58	68	70
05/12	114	91	95	104	101
05/24	88	82	67	82	80
05/28	81	70	84	82	79
06/01	45	46	46	55	48
06/05	107	88	83	77	89
06/09	75	70	80	95	80
06/13	99	82	72	83	84
06/21	86	78	80	81	81
06/25	68	64	60	66	64
Fall					
09/01	97	94	97	112	100
09/09	80	68	76	79	76
09/17	81	70	77	88	79
09/21	106	87	99	97	97
09/29	122	103	89	102	104
10/03	--	41	56	84	61
10/11	108	100	101	91	100
10/15	78	66	77	89	77
10/19	111	100	81	106	99
10/27	110	92	98	105	101
Spring	84	74	73	79	78
Fall	99	82	85	95	89
Annual	91	78	79	87	84

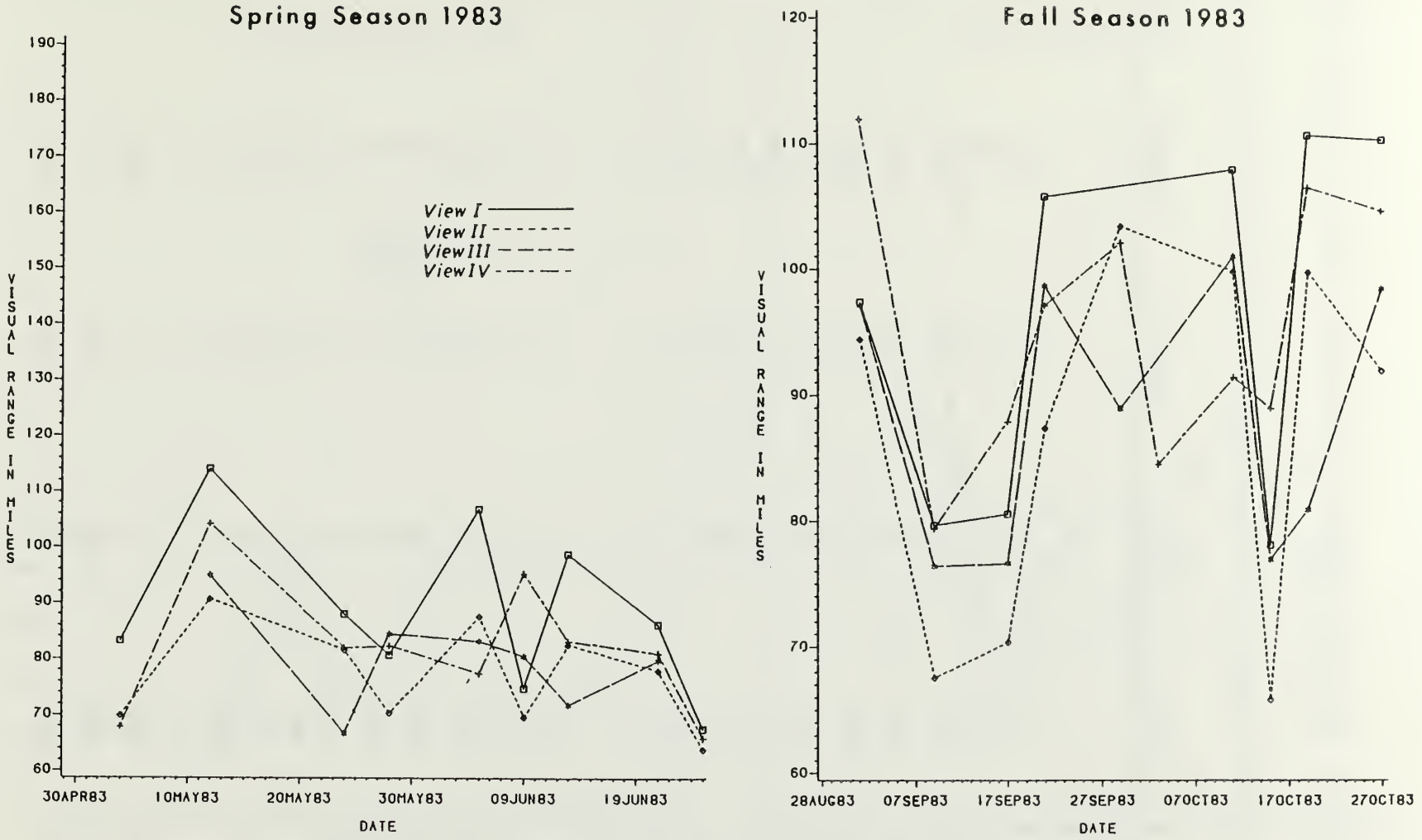

Figure 2-8. Daily Mean Visual Range for Each View, Piceance Basin, 1983.

Table 2-29. Daily and Seasonal Visual Ranges (miles) in Piceance Basin by View in 1984

Date	View I	View II	View III	View IV	All Views
Spring					
05/10	77	74	76	106	83
05/14	76	72	75	88	78
05/18	68	63	79	115	81
05/22	74	70	70	94	77
05/26	100	95	91	107	98
05/30	81	76	78	91	81
06/11	99	87	81	104	93
06/15	73	71	74	98	79
06/19	79	76	76	102	83
06/27	73	68	68	93	75
Fall					
09/07	144	121	91	83	110
09/15	81	70	71	90	78
09/19	92	77	88	123	95
09/23	66	56	65	68	64
09/27	80	74	73	85	78
10/05	58	49	53	66	57
10/09	86	74	81	89	82
10/13	91	68	64	89	78
10/25	48	41	39	47	44
Spring	80	75	77	100	83
Fall	83	70	69	82	76
Annual	82	73	73	91	80

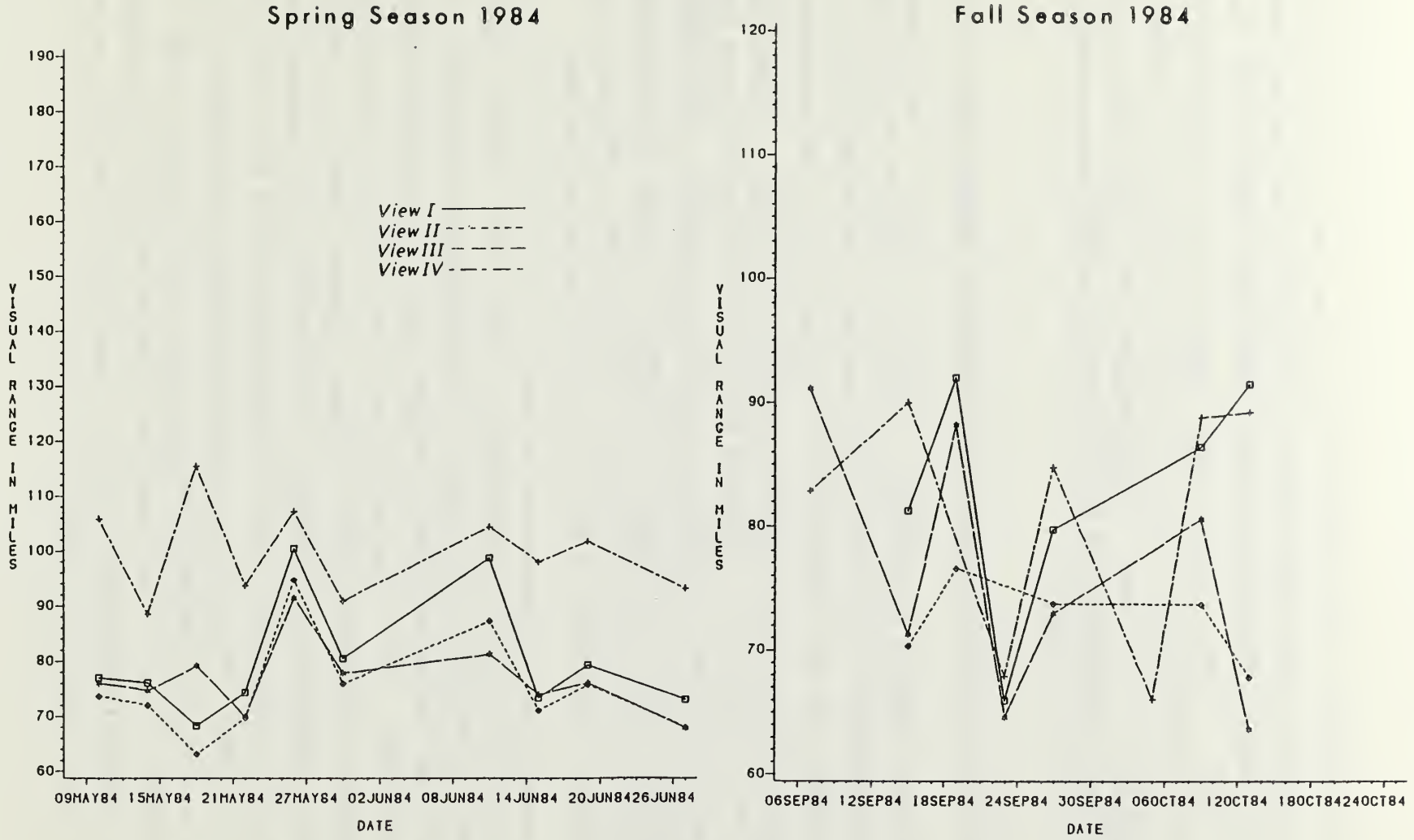

Figure 2-9. Daily Mean Visual Range for Each View, Piceance Basin, 1984.

high variability: the 1983 annual mean visual range is 84 miles with the daily visual range varying from 48 to 104 miles, while the 1984 annual mean visual range is 80 miles with a daily mean visual range varying from 44 to 110 miles. In 1983, the mean visual range for fall is higher than spring (89 vs. 78 miles), but in 1984 the reverse is true (76 vs. 83 miles). The annual mean visual ranges for 1983 and 1984 are slightly below the 1975-1982 annual mean visual range of 87 miles, but are within the historical variation of the data record.

Correlation of Visibility and Particulate Matter Concentration

The special studies program which collects TSP, PM_{10} and PM_6 data from colocated samplers (see Section 6.5) provided a unique opportunity to test the theory that the concentration of fine particles in the atmosphere has a greater effect on visibility than the TSP concentration. The particulate monitoring program was coordinated with the visibility monitoring program, so that data in both programs were taken simultaneously. A PM_{10} monitor was installed at Site 1 colocated with TSP monitor in late 1983, so correlations could be run on the PM_{10} data both in 1983 and 1984. A PM_6 monitor was installed in late 1984, so PM_6 data are only available from 1984.

The correlation results are presented in Table 2-30. The first point evident in the table is that many of the correlations are negative, indicating an inverse relationship between visibility and particulate matter concentration. This is not surprising, since visibility should decrease as atmospheric particulate matter increases. However, there is a dramatic decrease between the correlations in 1983 and 1984. For instance, the correlation between View I and TSP concentration drops from -0.52 in 1983 to -0.03 in 1984. Similarly, the correlation between the average of all four views and the PM_{10} concentration drops from -0.34 in 1983 to -0.08 in 1984. The reason for this is not known, but it may be related to the presence of other important interfering variables, uncertainty in the data, or the fairly small sample size (n=19).

Table 2-30. Correlation of Average Daily Visual Range in Piceance Basin and 24-hour TSP, PM_{10} and PM_6 Concentrations at Site 1.

Date	Visual Range View I	View II	View III	View IV	Average All Views
1983					
TSP Concentration	-0.52	-0.28	-0.15	-0.25	-0.29
PM_{10} Concentration	-0.52	-0.33	-0.15	-0.30	-0.34
1984					
TSP Concentration	-0.03	0.16	0.25	0.16	0.13
PM_{10} Concentration	-0.30	-0.13	0.12	0.17	-0.08
PM_6 Concentration	-0.33	-0.01	0.06	0.13	-0.03

It is important to note that although some of the correlation results are somewhat inconsistent and even difficult to explain (such as the positive correlations between particulate concentrations and visual range), only two of the correlations were statistically significant at the 10 percent level: visual range at View I vs. TSP concentrations, and visual range at View I vs. PM_{10} concentrations during 1983. View I, oriented NNW of the visibility monitoring site, passes 8 miles to the east of Tract C-a (Figure 2-7). The other views, oriented N to ENE, do not pass nearly as close to Tract C-a. Consequently, the particulate concentration measured at Site 1 should be most representative of conditions along View I.

The correlation of visual range along View I and the TSP and PM_{10} concentrations for 1983 were identical at -0.52. This indicates that only 27 percent of the variation (r^2) in TSP and PM_{10} concentrations were associated with variations in the visual range along View I.

In summary, the correlations between visual range and particulate matter concentration were low and not statistically significant, with two exceptions. There are several possible reasons for these low correlations:

1) None of the Hi-Vol monitors (TSP, PM_{10} or PM_6) directly measure those particles below 1 um in diameter which are most effective in reducing atmospheric visibility, although the PM_6 monitor, with a 50 percent cutpoint at 6 um, comes closest.

2) The TSP, PM_{10} and PM_6 monitors take point measurements that may not be representative of particulate concentrations along the four views. They also average particulate concentrations over 24 hours, whereas the visual ranges are averages of seven instantaneous measurements taken during daylight hours.

3) Meteorological conditions, which strongly affect visibility, are not considered in this correlation.

2.6 SUMMARY

Both air quality and meteorological data were collected at a site near Tract C-a during 1984. With approval of the Oil Shale Projects Office, the air quality monitors were shut down on July 1, 1984. The meteorological and TSP monitoring program was operational for the entire year. No violation of any National Ambient Air Quality Standard (NAAQS) was detected during the six months in which air quality data were collected. Considering the very low activity level on and around the tract, this result is not surprising. With the exception of ozone and total suspended particulates (TSP), concentrations of all air quality parameters were found to be near or below the threshold of detection of the state-of-the-art instruments used in the monitoring program.

The range of ozone concentrations recorded during the first six months of 1984 was 0.026 to 0.077 ppm. This range is very similar to that found in previous years, and did not appear to be influenced by the decrease in site activity. This lends support to the hypothesis advanced in earlier reports that the source of the ozone concentrations is located elsewhere (e.g., ozone is brought in by long range transport or stratospheric injection).

Both peak summertime and annual geometric mean TSP concentrations in 1984 have dropped substantially. Maximum 24-hr TSP concentrations and annual geometric mean concentrations were 25 and 12 percent of their respective secondary NAAQS. At present, both TSP sites are measuring primarily background concentrations, with little impact due to localized activity. The correlation of the two TSP data sets on an annual basis was high at 0.85.

The meteorological data showed that 1984 had the lowest average temperature and was the wettest year on record. The average temperature of 5.9^{o}C was a record by 0.2^{o}C, and the precipitation total of 22 inches was more than an inch above the previous high. Review of the meteorological record did not reveal extreme temperatures in comparison with previous years; the lower temperatures and higher precipitation resulted from cloudier weather, particularly in the spring and summer. The most common wind directions were

south-southwest to west, which has been the case for the entire period of record. Average wind speed at the 10-m level during 1984 was 6.3 mph.

Based upon a regression analysis of a four-year record (1979-1982) of telephotometric and photometric data, a set of "equivalent" telephotometric data were calculated from photographic data taken in 1975-76 and 1978. Along with the 1975-76 and 1978 data sets, the 1983 and 1984 telephotometric data presented in this monitoring report complete an eight-year record of consistent visibility data. Average visual ranges for 1983 and 1984 were high (84 and 80 miles, respectively) and very similar to averages from previous years. A regression analysis of TSP and inhalable particulate data with the 1983 and 1984 visibility data resulted in relatively low and inconsistent correlations that were generally not significant. Apparently other factors, such as meteorology, have a more direct influence on visibility in an area with good air quality such as the Piceance Basin.

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SECTION 3
TERRESTRIAL STUDIES

3.0 INTRODUCTION

The objectives of the Terrestrial Studies portion of the MDP Environmental Monitoring Program are to conduct monitoring required by the environmental stipulations in the Tract C-a lease, and to detect and evaluate possible changes (as a result of development-related impact) in the vegetative or faunal components of the terrestrial ecosystems on or near Tract C-a.

The sampling program associated with the Terrestrial Studies is geared to the seasonal cycles of the ecosystems involved. The design of the program is based on current knowledge of Tract C-a ecosystems and RBOSC project development plans. As the development of Tract C-a is a pioneering effort, such development plans are subject to frequent modification. The basic knowledge of Tract C-a ecosystems is also increasing. These factors result in frequent changes to the Terrestrial Studies portion as well as other components of the MDP Environmental Monitoring Program.

Further sampling associated with the Terrestrial Studies Program has been deferred until from 6 months to a year prior to the beginning of construction on Tract C-a. Therefore, none of the Terrestrial Studies programs was sampled during 1984.

SECTION 4
AQUATIC STUDIES

4.0 INTRODUCTION

The MDP Aquatic Monitoring Program is designed to provide information on the aquatic ecosystems in the vicinity of Tract C-a. The primary purpose of this program is to identify and measure the potential effects on the stream systems that may be the result of oil shale development.

Further sampling associated with the Aquatic Monitoring Program has been deferred until from 6 months to a year prior to the beginning of construction on Tract C-a. Therefore, none of the Aquatic Studies sampling locations was monitored during 1984.

SECTION 5
HYDROLOGY STUDIES

5.0 INTRODUCTION

During 1984, the hydrology monitoring program was conducted in accordance with the lease suspension period Scope of Work, Revision 7.0 (RBOSC 1983a) as amended June 29, 1984. The hydrology program focused on three elements:

1. Dewatering/Reinjection/Discharge Program
2. MIS Modular Development Area
3. MIS Retort Abandonment Program

Data on surface water, groundwater, and developmental activites monitoring are included in this section. Surface monitoring includes U.S.G.S. gaging stations, flumes, and springs and seeps, all on or near Tract C-a. Groundwater data were collected from alluvial, and upper and lower aquifer monitor wells. Developmental activities include sampling of dewatering and reinjection operations and the retort water evaporation ponds on Tract C-a.

The MIS retort abandonment program focuses on water associated with the in-situ retorts, mine water and groundwater in proximity to the retorts.

Data analyses and summaries are reported in this section. Raw data are listed in Appendix 5. Supplemental data on retort and mine water systems have been previously reported to the OSPO and are not duplicated here.

The hydrology monitoring stations have been classified as follows:

- Type I (Control) stations not expected to be influenced by a given set of development activities.

- Type II (Near-field) stations expected to detect direct, relatively short-term impacts, should impacts result from development; such stations are located generally close to and downgradient from development activities or operations.

- Type III (Far-field) stations expected to detect indirect or long-term impacts, should impacts result from development; such stations are generally located downgradient and relatively distant from development areas.

This grouping of monitoring stations allows for spatial and temporal comparisons of water quality and physical characteristics. Thus, baseline data (collected since 1974) can be compared to post-operational data, and control areas can be compared to potentially impacted areas.

5.1 DEWATERING/REINJECTION/DISCHARGE PROGRAM

1. Objectives

The objectives of this program are to monitor the operation of the dewatering/reinjection system, and to measure the effects on surface and groundwater systems.

2. Methods

The upper aquifer near the MIS area was dewatered during MIS operations and dewatering continued until retort abandonment activities commenced with flooding in June 1984. Prior to flooding, the dewatering/reinjection system maintained the cone-of-depression, reinjecting water down gradient from the MIS area at various points. The potential effects on groundwater from operation of this system are changes in water levels and/or surface flows. Field water quality parameters (pH, specific conductance and temperature) are also sampled along with water chemistry at selected sites. With this system not operating, the cone-of-depression has filled and groundwater levels have returned to near baseline levels. The potential effects are changes in surface flows and changes in water caused by refilling of the cone of depression. Sampling methods, locations and schedules are described in previous MDP monitoring reports (e.g., RBOSC, 1981), the Scope of Work (RBOSC, 1983), and the MIS Retort Abandonment Program dated April 29, 1984. Stations included in the lease suspension dewatering/reinjection/discharge monitoring program are listed along with the 1983 interim stations to reflect the changes:

Station Class	Station Identification			
	1983 Interim Program		1984 Lease Suspension Program	
Type I Control	Springs and Seeps		Springs and Seeps	
	SPG-3	SPG-5	SPG-3A	SPG-5
	SPG-4	SPG-MILL	SPG-4	SPG-MILL
	Deep Aquifer		Deep Aquifer	
	GS-M9U	CE-708U	GS-M10U	AM-3U
	GS-M10U	AM-3U	GS-M12U	
	GS-M12U	GS-9U	CE-708U	
Type II Near Field	Mine Seepage		Mine Seepage	
	Mine water and sour water sumps Composite reinjection (YCOINJ)		Mine water and sour water sumps Composite reinjection (YCOINJ)	
	Discharge Sites/Streams		Discharge Sites/Streams	
	YFLDIS		YFLDIS	
	Deep Aquifer		Deep Aquifer	
	GS-D1U	GS-D6U	GS-D1U	
	GS-D3U	GS-D8U	GS-D3U	
	GS-MDP2CU	CE-702U	GS-MDP2CU	
			CE-709U	
Type III Far Field	YLDEDGE - leading edge			
	Deep Aquifer		Deep Aquifer	
	GS-M3U		GS-M3U	
	CE-709U		GS-M9U	
	GS-17L			

3. Results and Discussion

The monitoring data have been examined for temporal and spatial variations. Temporal changes were examined by comparing 1984 univariate statistics (e.g., mean and maximum values) with similar statistics for previous years. The major focus of these evaluations was on comparison of 1983 and 1984 data sets, although longer term changes and trends were also examined.

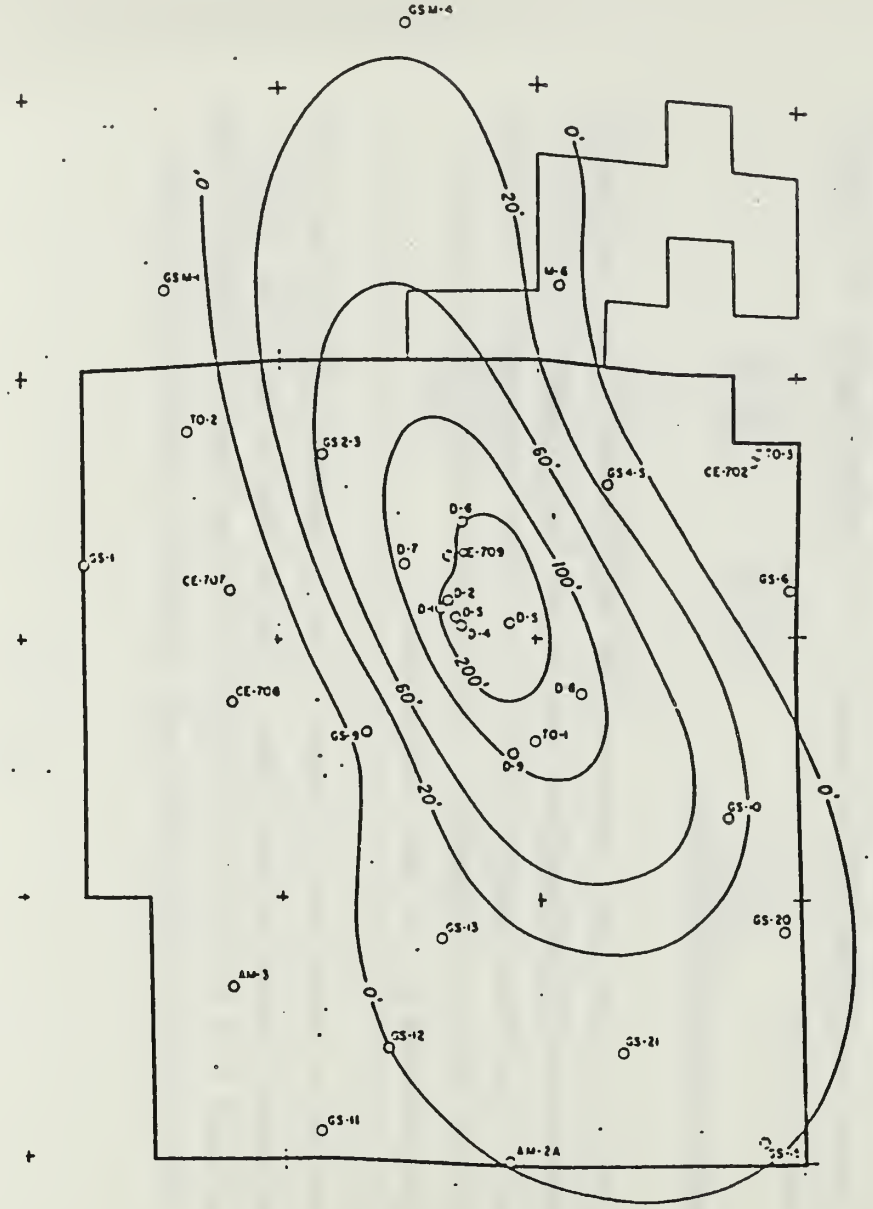
Extensive repetition of previously reported (pre-1984) data has been avoided. The 1983 data base is provided in MDP Monitoring Report 13 (RBOSC 1984b). Spatial changes were examined by comparison of univariate statistics for upper aquifer wells divided into control, near-field, and far-field station groups. In addition, a multivariate analysis of variance (MANOVA) procedure was used to test the significance of temporal and spatial variability and space-time interactions.

Unless noted otherwise, the parameters discussed and listed in this section and associated appendices have the following units: water chemistry constituents, milligrams per liter; mercury, micrograms per liter; pH, standard units; conductivity (specific conductance or ec), micromhos per cm; temperature, degree Celsius.

A. Dewatering/Reinjection System

During January to June 1984, dewatering was accomplished using mine sumps and dewatering wells. During June, pumping was intentionally discontinued resulting in significant modifications of the cone-of-depression. The 1984 contour lines (Figure 5-1) exhibit a significant filling of the cone-of-depression compared to the 1983 contour lines.

Total mine water production fluctuated slightly between 1,359 gpm and 1,514 gpm from January through mid-May 1984. From mid-May to late June, production decreased from a high of 1,483 gpm to zero gpm when the pumps were shut off. Since late June intermittent water production periods occurred from



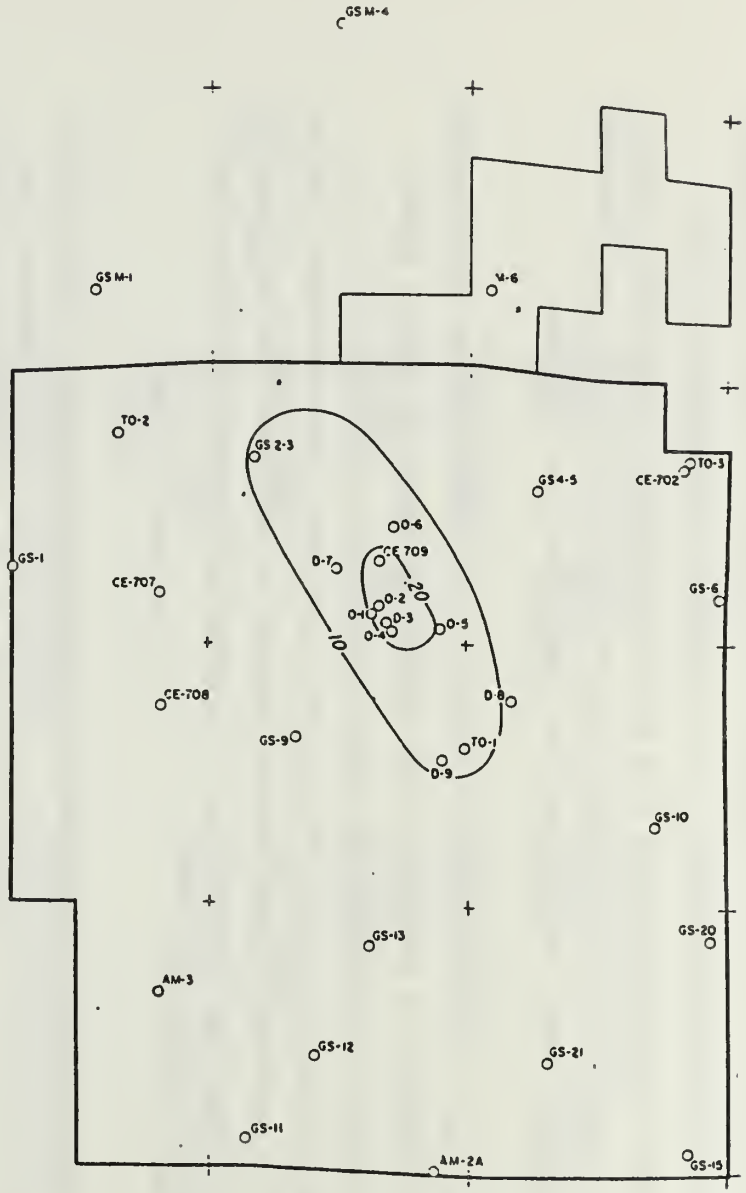


Figure 5-1. Upper Aquifer Cone of Depression

the mine: the first from mid-July to early August with an average production of 64 gpm, and the second from mid-November to mid-December with an average production of 57 gpm. The dewatering flows were entirely reinjected or consumed during 1984, resulting in no surface discharge.

Field measurements of mine water collected from the composite reinjection water (YCOINJ) are shown in Appendix 5-1.2. This water exhibited field conductivity measurements, ranging from 1,380 to 1,930 umhos/cm with a mean of 1,518 umhos/cm. This was a random variation, and not related to operations. The pH values which ranged from 7.1 to 8.2 with a mean of 7.8. These 1984 field measurements are very similar to the measurements obtained in 1983. Water chemistry for YCOINJ was also comparable to 1983 data (Appendix 5-1.1), indicating stable water quality conditions over time. 1984 means of major water chemistry constituents are compared to 1980-1983 means for YCOINJ:

Parameter	1984 Means	1980-1983 Means
TDS	1,070	1,026
alkalinity	500	472
calcium	54	42
magnesium	87	78
sodium	185	197
bicarbonate	587	547
sulfate	395	376

B. Springs/Seeps

Springs and seeps data are presented in Appendix 5-1.2. A new control area spring (SPG-3A) was monitored in 1984 to replace SPG-3 which went dry. SPG-3A is located one-half mile downstream from the SPG-3 site in Corral Gulch. The 1984 mean pH of the control springs was 7.6, comparable to the 1983 mean of 7.8. Conductivity means, however, rose slightly since 1983, from 1,404 to 1,788 umhos/cm, with increased conductivity means observed at each of the springs during 1984. Flow from SPG-5 has increased since 1983

while the remaining spring flows were not significantly different than previous years.

C. Upper Aquifer

1. Field Data

Data collected during 1984 are presented in Appendix 5-1.3. Summaries of these field data for control, near-field, and far-field station groups are presented in Table 5-1. Mean water levels and field water quality parameters cannot accurately be compared to the 1983 data due to changes in the stations monitored in 1984. These changes were made to reflect a focus on retort abandonment operations.

The 1984 summaries in Table 5-1 illustrate spatial gradients in the upper aquifer. Mean depth to water remains greater in the near-field area biased by the dewatering operations during the first half of 1984. Groundwater temperature was greater in the near-field area relative to the surrounding areas while conductivity and pH were highest in the far-field area.

2. Water Chemistry Data

Results of water chemistry analysis of upper aquifer samples in the 1984 dewatering/reinjection/discharge program are summarized in Table 5-2. Upper aquifer water chemistry data are presented in Appendix 5-1.1. The 1984 water chemistry means cannot accurately be compared to the 1983 means due to changes in the monitoring stations to reflect a focus on retort abandonment operations.

A spatial comparison of water chemistry parameters between control, near-field, and far-field areas shows conductivity, TDS, alkalinity, magnesium, bicarbonate and sulfate means increase from control to far-field areas. The calcium mean was highest in the near-field area, while pH and sodium means were lowest in the near-field.

Table 5-1. Summary of Field Data from Upper Aquifer Wells, Dewatering/Reinjection/Discharge Program, 1984.

TYPE = UPPER AQUIFER — AREA = CONTROL

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
FIELD WATER QUALITY PARAMETERS							
DEPTH TO WATER	11	146.5	179.5	428.10	25.50	25.5	428.1
WATER ELEVATION	5	6884.6	17.0	6900.00	6865.76	6865.8	6900.0
PH (STD. UNITS)	11	7.7	0.3	8.20	7.30	7.3	8.2
CONDUCTIVITY	11	1237.9	187.3	1569.00	1000.00	1000.0	1569.0
TEMPERATURE	11	10.6	1.6	12.90	8.40	8.4	12.9

TYPE = UPPER AQUIFER — AREA = NEAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
FIELD WATER QUALITY PARAMETERS							
DEPTH TO WATER	75	470.0	161.7	605.20	66.80	220.2	604.8
WATER ELEVATION	75	6409.5	109.0	6708.85	6308.15	6308.5	6583.9
PH (STD. UNITS)	11	7.2	0.2	7.60	6.90	6.9	7.6
CONDUCTIVITY	11	1790.7	269.1	2210.00	1300.00	1300.0	2210.0
TEMPERATURE	11	12.3	1.9	15.20	9.90	9.9	15.2

TYPE = UPPER AQUIFER — AREA = FAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
FIELD WATER QUALITY PARAMETERS							
DEPTH TO WATER	5	117.4	142.9	276.00	12.60	12.6	276.0
WATER ELEVATION	3	6309.2	0.4	6309.70	6309.00	6309.0	6309.7
PH (STD. UNITS)	5	8.4	1.5	9.60	6.60	6.6	9.6
CONDUCTIVITY	5	1996.4	905.3	3100.00	1300.00	1300.0	3100.0
TEMPERATURE	5	9.5	2.0	12.00	7.50	7.5	12.0

Table 5-2. Summary of Water Chemistry from Upper Aquifer Wells, Dewatering/Reinjection/Discharge Program, 1984.

TYPE = UPPER AQUIFER — AREA = CONTROL

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
BASIC WATER QUALITY PARAMETERS							
CONDUCTIVITY	7	1223.6	199.5	1575.00	1005.00	1005.0	1575.0
TOT. DIS. SOLIDS	7	816.1	158.4	1040.00	645.00	645.0	1040.0
PH	7	8.1	0.2	8.30	7.84	7.8	8.3
ALKALINITY	8	379.6	44.8	451.00	318.00	318.0	451.0
CALCIUM	8	43.9	15.6	61.00	26.00	26.0	61.0
MAGNESIUM	8	60.3	19.9	85.00	37.00	37.0	85.0
POTASSIUM	8	0.6	0.1	0.79	0.46	0.5	0.8
SODIUM	8	151.3	23.0	185.00	129.00	129.0	185.0
CHLORIDE	8	6.5	1.9	10.80	5.80	5.8	10.8
BICARBONATE	8	440.6	52.7	519.00	367.00	367.0	519.0
CARBONATE	7	1.0	0.0	1.00	1.00	1.0	1.0
SULFATES	8	312.5	105.7	454.00	202.00	202.0	454.0
SULFIDE	7	0.0	0.0	0.02	0.02	0.0	0.0
FLOURIDE	8	0.7	0.3	1.20	0.40	0.4	1.2
AMMONIA	8	0.4	0.3	0.96	0.13	0.1	1.0
BORON	8	0.2	0.1	0.27	0.08	0.1	0.3
LITHIUM	8	0.1	0.0	0.10	0.04	0.0	0.1
MOLYBDENUM	7	0.1	0.0	0.10	0.10	0.1	0.1
DIS. ORG. CARBON	8	8.9	4.7	15.00	2.00	2.0	15.0

TYPE = UPPER AQUIFER — AREA = NEAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
BASIC WATER QUALITY PARAMETERS							
CONDUCTIVITY	11	1854.5	268.2	2230.00	1360.00	1360.0	2230.0
TOT. DIS. SOLIDS	11	1449.1	350.4	2060.00	940.00	940.0	2060.0
PH	11	7.9	0.3	8.27	7.34	7.3	8.3
ALKALINITY	11	448.0	74.1	558.00	269.00	269.0	553.0
CALCIUM	11	145.1	66.7	252.00	75.00	75.0	252.0
MAGNESIUM	11	115.1	29.0	169.00	77.00	77.0	169.0
POTASSIUM	11	0.6	0.1	0.74	0.33	0.3	0.7
SODIUM	11	143.1	28.9	200.00	100.00	100.0	200.0
CHLORIDE	11	12.7	4.0	18.70	5.30	5.3	18.7
BICARBONATE	11	516.4	85.1	622.00	303.00	303.0	622.0
CARBONATE	11	1.0	0.0	1.00	1.00	1.0	1.0
SULFATES	11	703.6	260.2	1090	387.00	387.0	1090.0
SULFIDE	11	0.0	0.0	0.08	0.02	0.0	0.1
FLOURIDE	11	0.5	0.3	1.30	0.10	0.1	1.3
AMMONIA	11	0.1	0.1	0.45	0.05	0.0	0.4
BORON	11	0.2	0.0	0.26	0.20	0.2	0.3
LITHIUM	8	0.1	0.0	0.15	0.05	0.0	0.1
MOLYBDENUM	11	0.2	0.2	0.60	0.10	0.1	0.6
DIS. ORG. CARBON	11	8.5	11.5	42.00	2.00	2.0	42.0

TYPE = UPPER AQUIFER — AREA = FAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
BASIC WATER QUALITY PARAMETERS							
CONDUCTIVITY	4	2177.5	993.2	3100.00	1250.00	1250.0	3100.0
TOT. DIS. SOLIDS	4	1725.8	1006	2610.00	840.00	840.0	2610.0
PH	4	8.7	1.0	9.72	7.76	7.8	9.7
ALKALINITY	4	662.5	102.8	776.00	561.00	561.0	776.0
CALCIUM	4	137.4	155.0	290.00	3.90	3.9	290.0
MAGNESIUM	4	117.0	87.8	196.00	40.00	40.0	196.0
POTASSIUM	4	1.8	0.3	2.14	1.46	1.5	2.1
SODIUM	4	259.3	8.3	270.00	250.00	250.0	270.0
CHLORIDE	4	12.7	1.0	14.00	11.80	11.8	14.0
BICARBONATE	4	585.5	358.2	907.00	193.00	193.0	907.0
CARBONATE	4	100.3	123.2	255.00	1.00	1.0	255.0
SULFATES	4	706.5	611.4	1280	171.00	171.0	1280.0
SULFICE	4	0.2	0.2	0.43	0.02	0.0	0.4
FLOURIDE	4	0.8	0.6	1.50	0.10	0.1	1.5
AMMONIA	4	0.6	0.5	1.08	0.16	0.2	1.1
BORON	4	0.2	0.1	0.25	0.14	0.1	0.3
LITHIUM	4	0.1	0.0	0.14	0.11	0.1	0.1
MOLYBDENUM	4	0.1	0.0	0.20	0.10	0.1	0.2
DIS. ORG. CARBON	4	4.0	2.8	8.00	2.00	2.0	8.0

3. Statistical Analysis

The MANOVA for selected upper aquifer water chemistry constituents indicated significant variability for all constituents ($P > F = <.05$) in the area main effect except for fluoride. Significant variability for the year main effect was exhibited for chloride, fluoride, alkalinity and pH.

The Duncan's Multiple Range Test was used to examine the nature and significance of differences in mean concentrations of water chemistry over time (year) and space (control, near-field and far-field). Results are shown in Appendix 5-1.4. Mean concentrations of TDS, alkalinity, sulfate and conductivity showed significant spatial differences between all areas, increasing from control to far-field. This is the same trend exhibited by the 1983 data. Mean fluoride concentration exhibited no significant spatial differences. Among years, alkalinity, chloride and sodium showed high variability, while conductivity, TDS, calcium, sulfate, magnesium, fluoride and bicarbonate exhibited no significant differences. The 1984 means were not significantly different from previous year's means. The general water quality pattern has remained unchanged over time and this pattern cannot be related to operations involving the dewatering/reinjection system.

5.2 MIS MODULAR DEVELOPMENT AREA

1. Objectives

The lease suspension monitoring program of the MIS Modular Development area is designed to detect and evaluate any effects that the MIS retorts or surface operations have on deep aquifer, surface waters and alluvial aquifers. Sites monitored during 1984 included surface streams, springs, alluvial and deep aquifer wells.

2. Methods

Sampling methods are as described in previous reports and/or the Scope of Work (RBSOC 1983). Stations included in the lease suspension monitoring program are listed along with the 1983 interim station to reflect the changes:

Station Class	Station Identification	
	1983 Interim Program	1984 Lease Suspension Program
Type I Control	Streams	Streams
	B-USGS C-USGS	B-USGS C-USGS
	Springs and Seeps	Springs and Seeps
	SPG-3 SPG-4 SPG-14 SPG-5 SPG-MILL	SPG-3A SPG-4 SPG-14 SPG-5 SPG-MILL
	Alluvial Aquifer	Alluvial Aquifer
	GS-S7 GS-S8	GS-S7 GS-S8
	Deep Aquifer	Deep Aquifer
	GS-15L GS-15U CE-708U GS-9U	GS-D3U GS-D1U GS-15U
Type II Near Field	Streams	Streams
	D-USGS YMET3 YCOFL YBOXFL YSEOFL	D-USGS YMET3 YCOFL YBOXFL YSEOFL
	Alluvial Aquifer	Alluvial Aquifer
	GS-S27S GS-S27A	GS-S27S GS-S27A
	Deep Aquifer	Deep Aquifer
	CE-709U CE-702U GS-MDP2CU CE-705AU	CE-709U CE-702U GS-D5U GS-MDP2CU CE-705AU
Type III Far Field	Alluvial Aquifer	Alluvial Aquifer
	GS-S24	GS-S24
	Deep Aquifer	Deep Aquifer
	GS-M3U	GS-M3U GS-M9U

3. Results and Discussion

Temporal and spatial hydrologic variations have been examined for the MIS program element, using data from the above-listed stations. Temporal changes were examined by comparing 1984 univariate statistics with similar statistics for previous years, with the major focus on comparison with 1983 data. Extensive repetition of previously reported (pre-1984) data has been avoided. The 1983 data base used for comparison purposes in this report is provided in MDP Monitoring Report 13 (RBOSC 1984b). Spatial variations were evaluated by comparing control, near-field, and far-field univariate statistics for surface streams, alluvial wells and upper aquifer wells. An analysis of variance procedure was used to test the significance of observed variations and space-time interactions.

Unless noted otherwise, the parameters discussed and listed in this section and associated appendices have the following units: water chemistry constituents, milligrams per liter; mercury, micrograms per liter; pH, standard units; conductivity (specific conductance or ec), micromhos per cm; temperature; degrees Celsius.

A. Springs and Seeps

Five spring and seep monitoring stations functioned as control sites for the monitoring program of the MIS area. The field water quality measurements for each station are presented in Appendix 5-1.2. Mean conductivity increased from 1,435 umhos/cm in 1983 to 1,889 umhos/cm in 1984, and mean flow increased from 26.4 gpm to 43.3 gpm between 1983 and 1984. The 1984 pH mean of 7.5 was consistent with the 1983 mean.

B. Streams

Field measurements from the near-field stream stations are contained in Appendix 5-1.2. These stations include:

- YBOXFL - on Box Elder Gulch just upstream from the confluence with Corral Gulch

- YCOFL - on Corral Gulch just upstream from the confluence with Box Elder Gulch

- YMET3 - on Corral Gulch just below the confluence with Box Elder Gulch

- YSEOFL - on Corral Gulch approximately 1.5 miles below YMET3

The 1984 field measurements of pH and conductivity were consistent with 1983 data. Flows at the beginning of 1984 at all of these sites were higher than previous years due to heavy snowfall and precipitation in 1982 and 1983. Flumes became either silted-in or washed-out during the peak flow period beginning in late April continuing until August. Flows dropped to their lowest measurements in 1984 in December.

The 1984 water chemistry data from the surface flow stations is presented in Appendix 5-1.1. 1984 means at YBOXFL were generally consistent with 1983 means, while YCOFL showed higher means in 1984 for most parameters than were seen in 1983. Consequently, all water chemistry means at YMET3 were slightly higher in 1984 than in 1983, and most were higher at YSEOFL in 1984. Consistent with previous years, concentrations of major constituents increased between YMET3 and YSEOFL. Selected 1984 means were as follows:

Parameter	YMET3	YSEOFL
conductivity	1,603	2,034
TDS	1,173	1,544
pH	8.2	8.2
alkalinity	475	526
calcium	96	127
magnesium	85	114
sodium	176	213
bicarbonate	560	614
sulfate	487	685
DOC	8	10

MANOVA techniques were used to evaluate the temporal variability (1981 through 1984) at these stations (Appendix 5-1.4). All stations exhibited significant differences for sulfate among years. Magnesium, calcium, pH and TDS means were also highly variable among years at most stations, while all other major parameters exhibited no significant difference among years.

Data collected at the three USGS gage stations include daily flow, conductivity and temperature. The listing of this data along with time series plots can be found in Appendix 5-2.1. Data were available through September 1984.

Table 5-3 shows a summary of flows of waters, as measured at USGS gage stations entering and exiting Tract C-a using USGS gage station data. In general, the tract area was a net producer of surface water during 1984 (i.e., more water leaves than flows onto the tract area). In April, May and June, however, this situation was reversed probably reflecting local recharge.

Flows at the USGS sites were low from October 1983 through March 1984. In April, flows increased to their peak measurements on May 17 during heavy run-off: Station B in upper Corral Gulch peaked with a daily mean flow value of 44 cfs, Station C in Box Elder Gulch peaked at 69 cfs and Station D in lower Corral Gulch peaked at 95 cfs. The drainages returned to flows typical of previous years in September.

Daily field water quality means in 1984 were slightly higher than the 1983 means. The 1984 means for the USGS daily mean parameters are shown below:

Station	Flow (cfs)	Conductivity	Temperature(^{o}C)
B	5.05	1,433	7.6
C	5.37	1,279	8.6
D	9.21	1,548	10.3

Table 5-3. Summary of flows at USGS gage stations, 1984 water year.

Station	Flow (acre/ft)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
B - Corral Gulch - West	67.6	41.5	43.4	34.7	28.5	41.9	172.7	1256.7	706.3	265.3	150.9	83.0
C - Box Elder - West	0.0	0.0	0.0	0.0	0.0	0.0	212.4	1793.9	786.5	103.9	15.7	0.4
Total Inflow	67.6	41.5	43.4	34.7	28.5	41.9	385.1	3050.6	1492.8	369.2	166.6	83.4
D - Corral Gulch - East (total outflow)	148.9	118.8	106.7	95.6	81.8	91.1	362.7	2562.1	950.4	522.3	264.3	104.9
Outflow - Inflow	81.3	77.3	63.3	60.9	53.3	49.2	-22.4	-488.5	-542.4	153.1	97.7	21.5

Analysis of variance results indicated that the mean daily flows, conductivity and temperature were significantly different among report years for each USGS station, with all stations showing a PR > F value of 0.001 for each parameter. The results of the Duncan's Multiple Range Test (Appendix 5-2.1) indicated that flow means in 1984 were significantly higher from all other years analyzed for all stations. When considering seasonal flow variability, spring and summer are significantly different from all other seasons for stations B and D, while there is no variability between seasons at station C.

The Duncan's Multiple Range Test for mean conductivity by season indicates no significant difference between fall and summer for station B; summer and spring for station C and winter and fall for station D. Mean conductivity in 1984 was significantly higher than all years examined (1975-1983) at stations B and D, and the 1984 mean conductivity at station C was significantly higher than all other years except 1981. The mean conductivity of station B may be higher due to leaching of soils and other materials exposed after the 1983 mud slide in the upper reaches of Corral Gulch (above station B).

Water chemistry data collected during 1984 are found in Appendix 5-2.1. major water chemistry parameters are summarized for each station in Table 5-4. Most constituents analyzed were comparable to the 1983 analysis, although conductivity means were slightly higher at all sites in 1984. Station B exhibited the highest mean pH and conductance and the highest mean concentrations of calcium, magnesium, chloride and sulfate. Station D exhibited the highest mean concentration of alkalinity and sodium, while station C exhibited the lowest mean conductance.

The Duncan's Analysis (Appendix 5-2.1) for the year main effect showed no significant differences between years for pH, alkalinity, sodium, potassium and boron. The 1984 means were significantly greater than all other years for calcium, chloride and sulfate. The parameters showing no variability between stations were DOC, potassium, chloride and boron. The most variable constituent among stations was sodium.

Table 5-4. Summary of Water Chemistry from USGS Gage Stations, 1984.

U.S.G.S. GAGING STATION = B-CORRAL GULCH - WEST

REPORT YEAR = 1984

PARAMETER	N	MEAN	STD	MIN	MAX	P5	P95
CONDUCTIVITY	2	1640.00	70.71	1590.00	1690.00	1590.00	1690.00
PH	2	8.15	0.21	8.00	8.30	8.00	8.30
TOT DIS SOLIDS	0	.	.	.	.	.	.
ALKALINITY	2	291.50	37.48	265.00	318.00	265.00	318.00
AMMONIA	0	.	.	.	.	.	.
KJELDAHL N-623	2	1.80	1.13	1.00	2.60	1.00	2.60
DIS O_PHOSPHATE	1	0.08	.	0.08	0.08	0.08	0.08
DIS ORG CARBON	2	14.50	0.71	14.00	15.00	14.00	15.00
CALCIUM (CA)	2	155.00	7.07	150.00	160.00	150.00	160.00
MAGNESIUM (MG)	2	90.50	4.95	87.00	94.00	87.00	94.00
SODIUM (NA)	2	120.00	14.14	110.00	130.00	110.00	130.00
POTASSIUM (K)	2	1.70	0.28	1.50	1.90	1.50	1.90
CHLORIDE (CL)	2	24.50	4.95	21.00	28.00	21.00	28.00
SULFATE (SO4)	2	565.00	63.64	520.00	610.00	520.00	610.00
FLUORIDE (F)	2	0.15	0.07	0.10	0.20	0.10	0.20
BORON (B)	2	105.00	7.07	100.00	110.00	100.00	110.00

U.S.G.S. GAGING STATION = C-BOX ELDER GULCH - WEST

REPORT YEAR = 1984

PARAMETER	N	MEAN	STD	MIN	MAX	P5	P95
CONDUCTIVITY	1	1180.00	.	1180.00	1180.00	1180.00	1180.00
PH	1	8.10	.	8.10	8.10	8.10	8.10
TOT DIS SOLIDS	0	.	.	.	.	.	.
ALKALINITY	1	297.00	.	297.00	297.00	297.00	297.00
AMMONIA	0	.	.	.	.	.	.
KJELDAHL N-623	1	1.00	.	1.00	1.00	1.00	1.00
DIS O_PHOSPHATE	1	0.02	.	0.02	0.02	0.02	0.02
DIS ORG CARBON	1	15.00	.	15.00	15.00	15.00	15.00
CALCIUM (CA)	1	120.00	.	120.00	120.00	120.00	120.00
MAGNESIUM (MG)	1	66.00	.	66.00	66.00	66.00	66.00
SODIUM (NA)	1	75.00	.	75.00	75.00	75.00	75.00
POTASSIUM (K)	1	1.30	.	1.30	1.30	1.30	1.30
CHLORIDE (CL)	1	17.00	.	17.00	17.00	17.00	17.00
SULFATE (SO4)	1	340.00	.	340.00	340.00	340.00	340.00
FLUORIDE (F)	1	0.20	.	0.20	0.20	0.20	0.20
BORON (B)	1	80.00	.	80.00	80.00	80.00	80.00

U.S.G.S. GAGING STATION = D-CORRAL GULCH - EAST

REPORT YEAR = 1984

PARAMETER	N	MEAN	STD	MIN	MAX	P5	P95
CONDUCTIVITY	3	1613.33	165.03	1430.00	1750.00	1430.00	1750.00
PH	3	8.03	0.06	8.00	8.10	8.00	8.10
TOT DIS SOLIDS	0	.	.	.	.	.	.
ALKALINITY	3	400.33	89.37	319.00	496.00	319.00	496.00
AMMONIA	0	.	.	.	.	.	.
KJELDAHL N-623	2	0.80	0.42	0.50	1.10	0.50	1.10
DIS O_PHOSPHATE	3	0.03	0.01	0.02	0.04	0.02	0.04
DIS ORG CARBON	3	10.07	3.90	6.20	14.00	6.20	14.00
CALCIUM (CA)	3	103.33	15.28	90.00	120.00	90.00	120.00
MAGNESIUM (MG)	3	82.33	5.51	77.00	88.00	77.00	88.00
SODIUM (NA)	3	156.67	40.41	110.00	180.00	110.00	180.00
POTASSIUM (K)	3	2.30	1.14	1.50	3.60	1.50	3.60
CHLORIDE (CL)	3	17.67	4.04	13.00	20.00	13.00	20.00
SULFATE (SO4)	3	480.00	55.68	430.00	540.00	430.00	540.00
FLUORIDE (F)	3	0.40	0.20	0.20	0.60	0.20	0.60
BORON (B)	3	140.00	45.83	90.00	180.00	90.00	180.00

C. Alluvial Aquifers

1. Field Data

Field measurements data for alluvial wells are listed in Appendix 5-1.3. Mean water level measurements (depth to water) during 1984 (Table 5-5) were consistent with the 1983 mean water levels in the control and far-field areas. The near-field water level mean rose from 20.4 feet in 1983 to 17.2 feet in 1984. The water levels rose appreciably in these near-field wells in July after the dewatering system was shut off in June.

The 1984 field parameters of alluvial aquifers for all areas were comparable to the 1983 data, except for mean conductivities in the control and near-field wells, which were higher than seen in 1983. This could be attributable to leaching of materials from surrounding soils after two years of heavy snowmelt.

As seen in previous years, measurements of alluvial pH for 1984 showed no spatial variation across the three monitoring areas. Conductivity was highest in the near-field area and lowest in the control area during the year.

2. Water Chemistry Data

Water chemistry data for alluvial wells are presented in Appendix 5-1.1. The limited sampling of the alluvial wells in 1984 showed the near- and far-field analysis consistent with the 1983 analysis. The exception to this was increased pH in both areas, where the mean pH rose from 7.3 to 8.2 in the near-field wells and from 7.2 to 8.2 in the far-field wells between 1983 and 1984. Summaries of water chemistry for the near- and far-field alluvial wells are shown in Table 5-6.

Table 5-5. Summaries of field data from alluvial wells, MIS monitoring program, 1984.

TYPE = ALLUVIAL AQUIFER AREA = CONTROL

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
FIELD WATER QUALITY PARAMETERS							
DEPTH TO WATER	24	28.8	7.9	38.40	17.70	18.2	38.4
WATER ELEVATION	0	.	.	.	.	.	.
PH (STD. UNITS)	6	7.3	0.2	7.60	7.00	7.0	7.6
CONDUCTIVITY	6	1500.0	251.0	1900.00	1250.00	1250.0	1900.0
TEMPERATURE	6	9.1	1.4	11.40	7.60	7.6	11.4

TYPE = ALLUVIAL AQUIFER AREA = NEAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
FIELD WATER QUALITY PARAMETERS							
DEPTH TO WATER	14	17.2	3.4	19.40	6.70	6.7	19.4
WATER ELEVATION	0	.	.	.	.	.	.
PH (STD. UNITS)	5	7.3	0.2	7.50	7.00	7.0	7.5
CONDUCTIVITY	5	2000.0	913.1	3500.00	1400.00	1400.0	3500.0
TEMPERATURE	5	9.8	0.8	10.80	8.70	8.7	10.8

TYPE = ALLUVIAL AQUIFER AREA = FAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
FIELD WATER QUALITY PARAMETERS							
DEPTH TO WATER	4	9.9	0.9	10.80	8.70	8.7	10.8
WATER ELEVATION	0	.	.	.	.	.	.
PH (STD. UNITS)	3	7.5	0.2	7.70	7.30	7.3	7.7
CONDUCTIVITY	3	1800.0	100.0	1900.00	1700.00	1700.0	1900.0
TEMPERATURE	3	9.0	0.9	9.90	8.10	8.1	9.9

Table 5-6. Summary of water chemistry data for alluvial wells, MIS monitoring area, 1984.

TYPE = ALLUVIAL AQUIFER AREA = NEAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
BASIC WATER QUALITY PARAMETERS							
CONDUCTIVITY	1	1580.0	.	1580.00	1580.00	1580.0	1580.0
TOT. DIS. SOLIDS	1	1090.0	.	1090.00	1090.00	1090.0	1090.0
PH	1	8.2	.	8.24	8.24	8.2	8.2
ALKALINITY	1	475.0	.	475.00	475.00	475.0	475.0
CALCIUM	1	97.0	.	97.00	97.00	97.0	97.0
MAGNESIUM	1	85.0	.	85.00	85.00	85.0	85.0
POTASSIUM	1	2.3	.	2.31	2.31	2.3	2.3
SODIUM	1	140.0	.	140.00	140.00	140.0	140.0
CHLORIDE	1	11.3	.	11.30	11.30	11.3	11.3
BICARBONATE	1	559.0	.	559.00	559.00	559.0	559.0
CARBONATE	0	.	.	.	.	.	.
SULFATES	1	442.0	.	442.00	442.00	442.0	442.0
SULFIDE	1	0.0	.	0.03	0.03	0.0	0.0
FLOURIDE	1	0.3	.	0.30	0.30	0.3	0.3
AMMONIA	1	0.3	.	0.26	0.26	0.3	0.3
BORON	1	0.3	.	0.27	0.27	0.3	0.3
LITHIUM	0	.	.	.	.	.	.
MOLYBDENUM	0	.	.	.	.	.	.
DIS. ORG. CARBON	1	4.0	.	4.00	4.00	4.0	4.0

TYPE = ALLUVIAL AQUIFER AREA = FAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
BASIC WATER QUALITY PARAMETERS							
CONDUCTIVITY	1	1620.0	.	1620.00	1620.00	1620.0	1620.0
TOT. DIS. SOLIDS	1	1320.0	.	1320.00	1320.00	1320.0	1320.0
PH	1	8.2	.	8.18	8.18	8.2	8.2
ALKALINITY	1	577.0	.	577.00	577.00	577.0	577.0
CALCIUM	1	110.0	.	110.00	110.00	110.0	110.0
MAGNESIUM	1	102.0	.	102.00	102.00	102.0	102.0
POTASSIUM	1	2.0	.	2.02	2.02	2.0	2.0
SODIUM	1	180.0	.	180.00	180.00	180.0	180.0
CHLORIDE	1	14.0	.	14.00	14.00	14.0	14.0
BICARBONATE	1	681.0	.	681.00	681.00	681.0	681.0
CARBONATE	0	.	.	.	.	.	.
SULFATES	1	551.0	.	551.00	551.00	551.0	551.0
SULFIDE	0	.	.	.	.	.	.
FLOURIDE	1	0.3	.	0.30	0.30	0.3	0.3
AMMONIA	1	0.1	.	0.14	0.14	0.1	0.1
BORON	1	0.2	.	0.18	0.18	0.2	0.2
LITHIUM	1	0.0	.	0.01	0.01	0.0	0.0
MOLYBDENUM	0	.	.	.	.	.	.
DIS. ORG. CARBON	1	11.0	.	11.00	11.00	11.0	11.0

3. Statistical Analysis

The results of the alluvial aquifer MANOVA for water chemistry constituents indicated that the majority of major constituents were significantly variable ($P > F = <0.05$) for the main effects of area (control, near- and far-fields) and year. This analysis is essentially the same as was seen after the 1983 analysis, indicating the spatial pattern of alluvial water quality variability has not changed significantly over time.

A Duncan's Multiple Range Test was used to examine the nature and significance of differences in means of alluvial water quality (Appendix 5-1.4). As seen in previous years, all areas were significantly different from each other for TDS, conductivity, magnesium, bicarbonate and sulfate. 1984 was significantly greater from all other years for TDS, pH and bicarbonate. Chloride was the only constituent with no variability between years.

D. Upper Aquifer

1. Field Data

Summaries of field data from control, near-field and far-field areas for the upper aquifer are shown in Table 5-7. Field measurements by station are found in Appendix 5-1.3. 1984 water level and field water quality means cannot accurately be compared to the 1983 means due to changes in the monitoring stations to reflect a focus on retort abandonment operations. Compared spatially, the near-field area exhibited the lowest means for pH and conductivity.

2. Water Chemistry

Upper aquifer water chemistry data are presented in Appendix 5-1.1. Summaries of these data by area are seen in Table 5-8. Water chemistry means from 1984 cannot accurately be compared to 1983 means due to changes in the monitoring stations to reflect a focus on retort abandonment operations.

Table 5-7. Summary of field data from upper aquifer wells, MIS monitoring area, 1984.

TYPE = UPPER AQUIFER AREA = CONTROL

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
FIELD WATER QUALITY PARAMETERS							
DEPTH TO WATER	40	548.8	98.7	605.20	206.50	283.7	605.0
WATER ELEVATION	40	6369.5	113.1	6706.85	6308.15	6308.4	6696.9
PH (STD. UNITS)	8	7.7	0.7	9.30	7.10	7.1	9.3
CONDUCTIVITY	8	1898.4	369.5	2400.00	1300.00	1300.0	2400.0
TEMPERATURE	8	13.3	1.3	15.20	11.00	11.0	15.2

TYPE = UPPER AQUIFER AREA = NEAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
FIELD WATER QUALITY PARAMETERS							
DEPTH TO WATER	78	248.4	186.9	550.90	24.60	26.6	546.4
WATER ELEVATION	78	6529.2	100.5	6708.85	6366.89	6371.4	6701.3
PH (STD. UNITS)	14	7.4	0.4	8.10	6.90	6.9	8.1
CONDUCTIVITY	14	1628.4	318.5	2245.00	1150.00	1150.0	2245.0
TEMPERATURE	14	11.5	1.8	14.30	9.30	9.3	14.3

TYPE = UPPER AQUIFER AREA = FAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
FIELD WATER QUALITY PARAMETERS							
DEPTH TO WATER	5	117.4	142.9	276.00	12.60	12.6	276.0
WATER ELEVATION	3	6309.2	0.4	6309.70	6309.00	6309.0	6309.7
PH (STD. UNITS)	5	8.4	1.5	9.60	6.60	6.6	9.6
CONDUCTIVITY	5	1996.4	905.3	3100.00	1300.00	1300.0	3100.0
TEMPERATURE	5	9.5	2.0	12.00	7.50	7.5	12.0

Table 5-8. Summary of water chemistry from upper aquifer wells, MIS monitoring area, 1984.

TYPE = UPPER AQUIFER — AREA = CONTROL

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
BASIC WATER QUALITY PARAMETERS							
CONDUCTIVITY	7	2013.6	353.6	2500.00	1360.00	1360.0	2500.0
TOT. DIS. SOLIDS	7	1565.7	304.5	1870.00	940.00	940.0	1870.0
PH	7	7.9	0.3	8.27	7.34	7.3	8.3
ALKALINITY	7	425.4	79.3	515.00	269.00	269.0	515.0
CALCIUM	7	125.6	77.1	252.00	61.00	61.0	252.0
MAGNESIUM	7	129.7	25.3	150.00	77.00	77.0	150.0
POTASSIUM	7	0.6	0.2	0.86	0.33	0.3	0.9
SODIUM	7	175.9	63.3	255.00	100.00	100.0	255.0
CHLORIDE	7	11.1	2.2	14.30	8.10	8.1	14.3
BICARBONATE	7	493.4	96.7	607.00	303.00	303.0	607.0
CARBONATE	7	1.0	0.0	1.00	1.00	1.0	1.0
SULFATES	7	819.4	209.7	1020	387.00	387.0	1020.0
SULFIDE	7	0.0	0.0	0.05	0.02	0.0	0.0
FLOURIDE	7	0.5	0.4	1.30	0.10	0.1	1.3
AMMONIA	7	0.2	0.2	0.45	0.05	0.0	0.4
BORON	7	0.2	0.0	0.29	0.20	0.2	0.3
LITHIUM	6	0.1	0.1	0.20	0.07	0.1	0.2
MOLYBDENUM	7	0.2	0.1	0.30	0.10	0.1	0.3
DIS. ORG. CARBON	7	9.7	14.3	42.00	3.00	3.0	42.0

TYPE = UPPER AQUIFER — AREA = NEAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
BASIC WATER QUALITY PARAMETERS							
CONDUCTIVITY	14	1634.6	304.5	2230.00	1220.00	1220.0	2230.0
TOT. DIS. SOLIDS	14	1207.3	361.3	2060.00	770.00	770.0	2060.0
PH	14	8.0	0.3	8.43	7.50	7.5	8.4
ALKALINITY	14	490.2	89.2	721.00	350.00	350.0	721.0
CALCIUM	14	105.4	61.0	232.00	31.00	31.0	232.0
MAGNESIUM	14	96.8	30.9	169.00	63.00	63.0	169.0
POTASSIUM	14	0.8	0.7	2.90	0.41	0.4	2.9
SODIUM	14	151.4	30.0	209.00	110.00	110.0	209.0
CHLORIDE	14	13.5	7.2	34.00	5.30	5.3	34.0
BICARBONATE	14	569.8	103.4	843.00	414.00	414.0	843.0
CARBONATE	14	2.1	3.0	12.00	1.00	1.0	12.0
SULFATES	14	500.0	224.6	1090	256.00	256.0	1090.0
SULFIDE	14	0.0	0.0	0.11	0.02	0.0	0.1
FLOURIDE	14	0.6	0.4	1.30	0.10	0.1	1.3
AMMONIA	14	0.1	0.1	0.29	0.05	0.0	0.3
BORON	14	0.2	0.1	0.27	0.05	0.0	0.3
LITHIUM	10	0.1	0.0	0.15	0.05	0.0	0.1
MOLYBDENUM	14	0.2	0.1	0.60	0.10	0.1	0.6
DIS. ORG. CARBON	14	6.1	3.2	13.00	2.00	2.0	13.0

TYPE = UPPER AQUIFER — AREA = FAR FIELD

PARAMETER	N	MEAN	STD	MAX	MIN	P5	P95
BASIC WATER QUALITY PARAMETERS							
CONDUCTIVITY	4	2177.5	993.2	3100.00	1250.00	1250.0	3100.0
TOT. DIS. SOLIDS	4	1728.8	1006	2610.00	840.00	840.0	2610.0
PH	4	8.7	1.0	9.72	7.76	7.8	9.7
ALKALINITY	4	668.5	102.8	776.00	561.00	561.0	776.0
CALCIUM	4	137.4	155.0	290.00	3.90	3.9	290.0
MAGNESIUM	4	117.0	87.8	196.00	40.00	40.0	196.0
POTASSIUM	4	1.8	0.3	2.14	1.46	1.5	2.1
SODIUM	4	259.3	8.3	270.00	250.00	250.0	270.0
CHLORIDE	4	12.7	1.0	14.00	11.80	11.8	14.0
BICARBONATE	4	585.5	358.2	907.00	193.00	193.0	907.0
CARBONATE	4	100.3	123.2	255.00	1.00	1.0	255.0
SULFATES	4	706.5	611.4	1280	171.00	171.0	1280.0
SULFIDE	4	0.2	0.2	0.43	0.02	0.0	0.4
FLOURIDE	4	0.8	0.8	1.50	0.10	0.1	1.5
AMMONIA	4	0.6	0.5	1.08	0.16	0.2	1.1
BORON	4	0.2	0.1	0.25	0.14	0.1	0.3
LITHIUM	4	0.1	0.0	0.14	0.11	0.1	0.1
MOLYBDENUM	4	0.1	0.0	0.20	0.10	0.1	0.2
DIS. ORG. CARBON	4	4.0	2.8	8.00	2.00	2.0	8.0

When compared spatially, pH, alkalinity and bicarbonate means increase from control to far-field areas. Conductivity, TDS, calcium, magnesium, sodium and sulfate means were lowest in the near-field area.

3. Statistical Analysis

The results of the MANOVA for selected water chemistry constituents indicate that, for most parameters, significant variability was observed in area, year and area X year main effects ($P > F = <0.05$). For area main effect, all constituents were significantly variable except for calcium, bicarbonate, sodium and fluoride. Significant temporal variability (year main effect) was noted for all constituents except TDS and conductivity. All years tested exhibited significant variability for the interaction term (year X area) except calcium and chloride.

A Duncan's Multiple Range Test (Appendix 5-1.4) showed these same results of significant differences between areas and report years. The highest variability over the years was exhibited by pH. The 1984 means are similar to 1978-1983 means for most major constituents, reflecting a fairly stable groundwater condition with no development-related impacts.

5.3 MIS RETORT ABANDONMENT

1. Objectives and Strategy

The abandonment of MIS retorts on Tract C-a was initiated in 1984. The basic goal of the retort abandonment program is to assure that retort materials do not present a hazard to historical water uses such as irrigation and livestock watering. The strategy is to remove sufficient soluble material from the retorts such that any subsequent releases would not result in harmful impacts to those water users. The approach taken is to:

1. Complete multicompletion monitor wells (RAM wells) in and near Retort 1 (completion data have been submitted to the BLM/OSPO).

2. Flood the retorts (initiated in May 1984).

3. Allow the flood waters to leach soluble materials from the in situ burned shale.

4. Pump the retort system, removing the retort leachate and discharging this wastewater to evaporation ponds (scheduled for the summer of 1985).

5. Allow the retorts to reflood.

6. Monitor the results of the flood/leaching process to evaluate its effectiveness and progress toward achieving the program goal.

2. Water Level and Flow Evaluations

Upon termination of pumping and initiation of flooding of the retort/mine system in May 1984, water levels rose steadily through 1984. Water levels in the mine (as measured in the Service-Production Shaft) rose at the same rate as water levels in the retort (as measured in the off-gas shaft; Figure

5-3). Water elevations increased by nearly 460 feet during the May 15 to July 15, 1984 period. Afterward, the rate of increase diminished totaling less than 70 feet between July 15 and the end of 1984. Water level elevations in the mine were generally about one foot above water levels measured in the off-gas shaft.

Soon after the completion of the RAM-7 monitor well in Retort 1, certain discrepancies were identified in the water level data. Water elevations measured in RAM-7 were on the order of one foot above those in the mine, indicating the potential for flow away from the retort toward the mine. The measured RAM-7 elevations were also higher than elevations measured in the off-gas shaft, which is open to the collection drift and bottom of the retort and which is used to track retort water elevations.

An analysis of densities was undertaken to clarify these apparent elevation differences. Water in the retort is warmer (tending to make it less dense than surrounding aquifer and mine water) and more saline (tending to make it more dense) than mine water. An analysis of these density differences was covered on a previous report to the BLM/OSPO (December 17, 1984) and will not be repeated in detail here.

This analysis of head data indicated that, when corrected for temperature and salinity, gradients near the retort are negligible (less than 0.1 foot) in the A- and B-grooves and in the C-zone. Since the hydraulics of the C-zone and its relationship to the upper aquifer is not well understood, the meaning of any C-zone gradient is unclear. Analysis of the G-zone data showed a 5 foot head difference between RAM-7G and RAM-2G, located just south of Retort 1. Water levels in RAM-2G have responded slowly to the flooding of the mine and retort, indicating low permeability in this zone and minimal connection with the retort system. The calculation for the mine and retort (RAM-7G) similarly showed essentially flat gradients between the retort and the mine. This indicates very slow groundwater flow in the mine-retort area. Details of the analysis are in a report to BLM/OSPO (December 17, 1984) and will not be repeated here.

Figure 5-3. Water Elevations in MIS Retort System, 1984.

The conclusion of essentially flat gradients near the mine and retort is a logical consequence of the filling of the cone-of-depression. It is not reasonable to expect a bulge in elevation right over Retort 1, which would indicate that all recharge in the area is straight down, through the 60 x 60 foot top of Retort 1. The density corrections appear to explain the measured differences.

The water level elevations measured on October 3, 1984 were as follows (uncorrected for temperature and salinity):

- Mine 6702.3 ft
- Retort (off-gas shaft) 6701.3 ft

From this analysis of temperature and salinity density effects, which in actuality show flat gradients, as long as the retort (off-gas shaft) and mine differences are on the order of one foot or so with the indicated gradient toward the retort, it would appear that true gradients have remained unchanged and are essentially flat in the vicinity of the retort and mine.

A. Head Differences

Part of the retort abandonment strategy was to mitigate groundwater flow through or from the retort, avoiding impacts on the upper aquifer until the leaching process is completed. Thus it is necessary to maintain little or no flow away from the retort and preferably to maintain flow toward the retort, by controlling water levels.

The head differences between the retort (RAM-7 wells) and the near-retort wells (RAM-2, -5, and -6) were evaluated to define groundwater gradients near the MIS retorts. Mean head differences, uncorrected for density differences, are listed in Table 5-9.

Measured head differences in the A-groove indicate that gradients away from the retorts existed when RAM-7 was completed in September 1984. The

Table 5-9. Head differences (uncorrected for temperature and salinity effects) between Retort 1 and near-retort monitor wells.

	Mean Head (Water Elevation) Differences (Feet) Between RAM Well Completions								
	A-Groove			B-Groove			C-Zone		
Month/Year	2A-7A	5A-7A	6A-7A	2B-7B	5B-7B	6B-7B	2C-7C	5C-7C	6C-7C
9/84	-0.3	-0.3	-0.5	-0.5*	-0.7*	-0.4*	0.4	-0.2	0.1
10/84	-0.7*	-0.7*	-0.8*	-0.7*	-1.0*	-0.7*	-0.2	-0.4*	-0.3*
11/84	0.1	-0.4	-0.8*	-1.0*	-0.8*	-0.6	0.2	-0.4*	-0.2
12/8	-0.9*	-1.0*	-1.0*	-0.8*	-1.0*	-0.8*	0.1	-0.5*	-0.3
1/85	-0.9*	-0.9*	-1.1*	-0.5*	-1.0*	-0.7*	0.3*	-0.3	-0.1

*mean for month is significantly different from zero (t - test at 0.05 level)

gradient may have increased from September 1984 to January 1985. However, from the earlier analysis of density effects, these data probably do not reflect true potential gradients because of the relatively greater water temperatures in the retort. From the earlier analysis of temperature and salinity effects, actual gradients, therefore, are much smaller than indicated in Table 5-9. The same conclusion is made for the groundwater gradients in the B-groove.

Measured near-retort gradients in the C-zone were typically not significantly different from zero (Table 5-9). Thus, given the density differences, as evaluated previously, actual gradients are probably toward the retort. This conclusion is supported by the water quality data collected for the C-zone wells, which show no influence from the retort system.

Because there are multiple water-bearing zones in the vicinity of the MIS retorts, vertical flow between zones may be important in evaluating potential impacts of abandonment. Vertical head gradients within Retort 1 are shown in Table 5-10. These data show a potential for flow from the A-groove to the B-groove within Retort 1, with a head difference of one-third to one-half foot. Temperature and salinity effects are probably not as important here as they are in evaluating retort-aquifer head differences.

The uncorrected head differences between the B-groove and the C-zone are not significantly different from zero. A small gradient may exist from the bottom of the retort (RAM-7G) to the C-zone. This flow potential, with that measured for the A- to B-groove, may result in a slight overall flow from retort top and bottom towards the middle (B-groove or C-zone).

The small head difference, and indicated flow from the A-groove to the B-groove was also observed for the near-retort monitor wells (RAM-2, -5 and -6; Table 5-11). Head differences of commonly a few tenths of a foot in RAM-2 and RAM-6, located to the south and east of the retorts, respectively. Somewhat larger head differences (some averaging over 0.5 feet between the A- and B-groove were observed in RAM-5, located north of Retort 1.

Table 5-10. Vertical head differences (uncorrected for temperature and salinity effects) in Retort 1 (RAM-7).

	Mean Head (Water Elevation) Differences (Feet) Between RAM-7 Completions		
Month/Year	7A-7B	7B-7C	7C-7G
9/84	0.3*	-0.1*	0.1
10/84	0.3*	-0.1	0.1
11/84	0.0	0.1	0.3*
12/84	0.5*	0.1	0.3*
1/85	0.5*	0.1	0.3*

*mean for month is significantly different from zero (t - test at 0.05 level)

Evaluation of water level data (uncorrected for temperature and salinity), at RAM-3 and -4, flow between the A- and B-groove is either negligible (head difference not significantly different from zero) or indicated to be from the B-groove to the A-groove. Thus vertical flows at these wells appear to be opposite that indicated in Retort 1 and in the near-retort wells.

Evaluation of heads in Retort 1 indicates no net flow between the B-groove and the C-zone (Table 5-10). Near-retort wells, and RAM-3 show gradients of a few tenths of a foot to about one foot between these zones, with an indicated flow direction from the C-zone upward to the B-groove segment of the upper aquifer (Table 5-11). Flow in RAM-4, further to the east of Retort 1, appears to be in the opposite direction, from the B-groove to the C-zone. The head difference at RAM-4 is over 1 foot (Table 5-11).

Comparison of water elevations in the C-zone and G-level of RAM-2 indicates a flow potential from C to G (Table 5-11). This may be a spurious indication caused by the slow water level recovery rate in the RAM-2G well relative to other RAM monitor wells.

This analysis of vertical head differences illustrates the complexity of the groundwater system in the vicinity of the MIS retorts. Vertical flow near the retorts appears to be toward the B-groove, with downward flow from the A-groove and upward flow from below. Further distant (a few hundred feet) from the retorts, in RAM-4, the flow is typically downward from the B-groove and also, at least occasionally, upward to the A-groove.

B. Other Tests

A series of pump tests (pumping from the retort product collection drift) were conducted in September and October 1984 to further evaluate groundwater hydraulics in the vicinity of the MIS retorts. The details have been provided to the BLM/OSPO and will not be repeated here. The results are summarized in the following paragraphs.

Table 5-11. Vertical head differences (uncorrected for temperature and salinity effects) between aquifer zones at RAM monitor wells.

Aquifer Zones	Month/Year	Mean Head (Water Elevation) Differences (Feet) Between RAM Well Completions RAM-2	RAM-3	RAM-4	RAM-5	RAM-6
A-B	5/84	139.6*	103.7*	154.7*	128.8*	141.6*
	6/84	65.6*	53.3*	71.9*	66.5*	67.3*
	7/84	0.3	-0.5*	-1.4*	0.4*	-0.1
	8/84	0.2*	-0.4*	-1.0*	0.5*	0.1
	9/84	0.4*	-0.2*	-0.5*	0.6*	0.1*
	10/84	0.3*	-0.3	-0.2	0.6*	0.2
	11/84	1.1	-0.1	-0.1	0.4	0.3*
	12/84	0.4*	-0.1	0.1	0.3	0.3*
	1/85	0.1	-0.3*	-0.3*	0.7*	0.1*
B-C	5/84	66.3*	46.4*	18.1*	123.9*	102.7*
	6/84	22.5*	12.7*	1.1	25.7*	21.1*
	7/84	-0.6*	-0.5*	2.7*	-0.3*	-0.8
	8/84	-0.8*	-0.1	2.2*	-0.5*	-0.7*
	9/84	-0.9*	-0.2	1.9*	-0.6*	-0.5*
	10/84	-0.5	-0.2*	1.2	-0.7*	-0.6*
	11/84	-1.1*	-0.3*	1.5*	-0.4	-0.5*
	12/84	-0.9*	-0.3*	0.5	--	-0.5*
	1/85	-0.7*	-0.3*	1.2*	-0.6*	-0.6*
C-G	5/84	115.8*				
	6/84	45.3*				
	7/84	20.5*				
	8/84	9.9*				
	9/84	6.2*				
	10/84	3.7				
	11/84	3.8*				
	12/84	2.3				
	1/85	2.9*				

*mean for month is significantly different from zero (t - test at 0.05 level)

Upon completion of the RAM-7 monitoring well in Retort 1 it was decided that a short term pump test would be desirable to determine pumping impacts on the retort and on water levels in the RAM-7 piezometers. Water levels in the RAM-7 piezometers essentially all responded identically to pumping on September 24 and 25, 1984. Water levels in the other RAM wells, 2B, 5B and 6B were affected by drawdown in the retort although not quite as much, typically 1.3 feet change compared to 1.9 feet in RAM-7 in the retort. Water levels in the off-gas shaft, which is directly connected to the retort product collection drift, dropped about 6.3 feet (versus 1.9 feet in RAM-7) indicating there is some permeability resistance and hence delayed response, between the off-gas shaft and the top of Retort 1. The drawdown in the off-gas shaft was more than expected and was not repeated in the follow-up pump test (see below).

The mine water level dropped about 0.9 feet (compared to 1.9 feet in RAM-7 and 6.3 feet in the off-gas shaft) during this pump test. This would indicate there is a definite connection between the retort and the mine systems.

Since the initial pump test indicated an impact of pumping on both the retort and the mine, it was decided to run another pump test of the retort system but with more attention to water level measurements and pumping rates. Thus, a 24-hour pump test (using the same pumping location) was set up with a more rigorous measurement schedule.

The pump test was started at 3:00 p.m. (1500) on September 27, 1984 with a pumping rate of 40 gpm initially. This pumping rate actually averaged 41.1 gpm over the 24-hour period of the pump test for a total withdrawal of 59,200 gallons. Data from this test have been transmitted to the BLM/OSPO.

Maximum drawdowns during the second pump test were as follows:

Location	Drawdown in Feet	Location	Drawdown in Feet
Mine	0.58	RAM-7C	1.40 (1.30)
Off-Gas Shaft	1.50	RAM-7G	1.71 (1.30)
Retort 1, Burner Hole C	1.42	RAM-2B	1.21
Retort 0	1.50	RAM-5B	1.22
RAM-7A	1.31	RAM-6B	1.27 (1.17)
RAM-7B	1.30		

The numbers in parenthesis reflect the drawdown at these locations at the end of the pump test which indicates that water levels in these wells had started to recover during the pump test. The above data indicate that the water level dropped about 1.50 feet in Retort 0, about 1.3 feet in the RAM-7 well piezometers in Retort 1, about 1.2 feet in the adjacent RAM wells, and about 0.6 feet in the mine.

A total of 59,200 gallons was pumped from the retort system. At the 6,700 foot level the open shafts, blast holes and burner holes have a volume of 582 gallons per foot. Therefore, the removal of 59,200 gallons would have caused a drop in water levels of 102 feet, or almost to the top of Retort 1, if there had been no inflow to the retort system. The results indicate there is considerable inflow into the retort system, at least 40.7 gpm of the average 41.1 gpm that was pumped. As the water levels in the retort system drop further below the water levels in the surrounding aquifer and mine even higher rates of inflow could be expected.

Based upon known retort and mine configurations and assumptions regarding the points at which water enters the retort, estimates of velocities, permeability and transmissivity were made. Using the combined thicknesses of the A- and B-groove aquifers (90 feet and 100 feet, respectively) the permeability and transmissivity is 2.9 feet per day (21.5 gal/ft^2/day) and 545 ft^2/day (4,077 gal/ft/day), respectively. With the retort dimensions

being 60 feet x 60 feet and intersecting 190 feet of the combined aquifer, the total inflow is approximately 980,000 gallons per day.

The permeability and transmissivity values estimated above are generally less than those previously estimated from short-term pumping test conducted on wells on-tract during the baseline studies. However, more recent data developed for the U.S. Geological Survey's groundwater model, and adopted to RBOSC's own groundwater model, would indicate permeabilities and transmissivities in the ranges estimated above.

The vertical permeability through the retort was also estimated. Using the 0.10 feet difference in head between the top and bottom of the retort, a permeability of 0.111 feet per second (1,196 gal/ft^2/day) can be calculated. This would indicate the total potential flow rate of the retort would be over 4 million gallons per day. This is about four times the inflow rate through the aquifers as indicated above.

The general conclusions are that water moves relatively freely from the mine area to the retort; judging from the magnitude and uniformity of response in near-retort wells, the A- and B-grooves appear to be the major points of entry into the retort: the transmissivity of the A- and B-groove aquifers is on the order of 4,000 gal/ft/day, thus potentially allowing up to about a million gallons per day to flow into Retort 1. The retort has a vertical permeability on the order of 1,200 gallons/ft^2/day, thus potentially allowing for four million gallons per day to flow through the retort. There is no readily apparent indication as to whether more of the inflow is through the A-groove aquifer or the B-groove aquifer. It does indicate the mine or aquifer must be dewatered at the time the retorts are pumped out or there will be too much water to handle through the retort pumping and evaporation system.

In discussions with personnel of the BLM/OSPO on October 26, 1984, RBOSC agreed to conduct a small scale pump test on the RAM-7 monitoring well in Retort 1 at Tract C-a. The purpose of the test was to determine if the vertical permeability of Retort 1 could be determined and if a negative

slope toward the center of Retort 1 could be maintained. Procedures and operations of the pump test are covered in a separate transmittal to the BLM/OSPO.

The maximum drawdown data, along with the water level time series, indicate that the retort system water levels dropped consistently, with no one level dropping more than the other. Total drop of the retort system water level was about one-half foot.

At the 6,710 level the static volumes within the retort system would be as follows: Retort 1 burner holes and blast holes - 45 gallons per foot, Retort 0 burner hole and blast holes - 67 gallons per foot, off-gas shaft 95 gallons per foot and instrument shaft - 375 gallons per foot, for a total of 582 gallons per foot. If there were no inflow into the retort system, the volume of water pumped, 8,110 gallons, should have lowered the retort system 13.93 feet rather than the 0.5 foot measured. This indicates appreciable groundwater flow into the retort, probably through the A- or B-groove.

The mine system water level dropped about 0.3 feet during this period. Prior readings of the mine and retort systems would indicate that water levels were rising at a rate of about 0.3 feet per 24 hours. Therefore, during the 8-hour pump test, the general water levels should have risen about 0.1 foot.

The monitor wells, RAM-2, -5 and -6, showed varying levels of drawdown, as would be expected. No one depth or zone seemed to be more influenced than another, except that the "surface" piezometers dropped less than the other zones, indicating that the water levels measured by the surface piezometers are not directly connected to the Upper Aquifer zones.

The pump test does show that with a pumping rate of 16 gpm, allowing for density differentials, a negative slope toward the center of the retort can be maintained. As a result, water would flow from the mine system to the retort system.

3. MIS Retort Water Quality

The RAM-7 well, with four completion zones in Retort 1, was completed in mid-September, 1984. The initial period of monitoring focused on measurement of water levels and verification of gradients in the vicinity of the retorts and mine. During this initial period, the wells were not sampled as this could have further complicated the water level data set. Initial samples were collected for on-site and laboratory chemical analysis on September 26, 1984. Discussion of results follow and data are listed in Appendix 5-3.1. Monitoring is continuing to track water quality in Retort 1.

A. On-Site Analysis - RAM-7

On-site analysis includes specific conductance (ec), potassium (K), pH, ammonia (NH_3), fluoride (F), sulfides, phenols and chemical oxygen demand (COD). Data for the report period are summarized below for each RAM-7 well completion zone. Data listings have been sent to the BLM/OSPO.

RAM-7A. Most of the initial (October 1984) measurements of specific conductance in RAM-7A were in the 11,000 to 12,000 micromhos per cm range. More recent observations may indicate a slow decreasing trend through the end of 1984, with December measurements averaging 9,150 micromhos per cm. It should be noted that the high pH values (>12) observed in RAM-7A probably result in spuriously high ec observations. This same trend was observed for the potassium concentration which initially increased from 740 to 900 mg/l in late October and then decreased to around 700 mg/l by the end of 1984. The ammonia concentration in RAM-7A was initially variable, ranging from 6.6 to 10.1 mg/l in October. However, more recent samples have been steady at about 6.5 to 7 mg/l.

Other on-site water quality analyses were steady during the report period as shown by the following 1984 ranges:

Temperature (°C)	29.0 to 31.8
pH	12.4 to 12.6
Fluoride (mg/l)	0.7 to 1.3
Phenols (mg/l)	0.2 to 1
COD (mg/l)	40 to 145

The 145 mg/l COD was the only measurement greater than 62 mg/l.

RAM-7B. In general, the on-site analysis of RAM-7B showed stable water quality, with no clear trends, during the report period. This is shown in the ranges:

Temperature (°C)	30.0 to 32.1
pH	11.1 to 11.7
Specific Conductance	5,331 to 6,703
Ammonia (mg/l)	5.4 to 8.8
Fluoride (mg/l)	2.0 to 3.6
Sulfide (mg/l)	<1 to 5
Potassium (mg/l)	670 to 900
Phenols (mg/l)	all observations = 1
COD (mg/l)	28 to 45

The relatively wide K range results from an increase to 900 mg/l in mid-November, followed by a decrease to near the 1984 mean (for RAM-7B) of 779 mg/l by the end of the year. As was observed in RAM-7A, ammonia concentrations in RAM-7B were initially variable but were steady near the year's mean (6.4 mg/l) by year's end.

RAM-7C. Water quality in RAM-7C was generally comparable to, though concentrations were slightly lower than, RAM-7B. No trends were evident.

RAM-7G. Water quality in RAM-7G was generally comparable to that observed in RAM-7B and -7C. The pH was slightly lower, averaging 9.1 while RAM-7B and -7C averaged 11.4 and 10.5, respectively. Also, the COD concentrations in RAM-7G were higher than observed in the upper zones of Retort 1. COD

averaged 86.3 mg/l in RAM-7G and about 39 to 52 in the other in-retort completions. This increase in organics near the bottom of Retort 1 is expected since the flame front probably did not completely sweep through this zone.

Statistical Analysis. To examine trends and potential interrelationships, linear regression parameters were estimated using on-site analysis data. Specific conductance (ec), potassium (K), COD, fluoride (F), ammonia (NH_3) and pH data were evaluated for trends in relation to water level (WL) and to date. In addition, potential interrelationships between specific conductance and potassium, COD and pH; between potassium and COD; and between fluoride and potassium were examined. The regression parameter examined was slope. Slopes significantly different from zero were identified and are listed (for RAM-7 well data) in Table 5-12.

These results (Table 5-12) indicate that most on-site analyses were stable through the report period, with no indicated trends related to the water level rise or to date. The few exceptions are listed on Table 5-12. RAM-7B exhibited an increasing trend of potassium concentration with both increasing water level and date. This indicated trend probably results from the increase in potassium concentrations from about 750 mg/l in mid-September to 900 mg/l in November (the maximum value for 1984). Concentrations declined after November.

The pH in RAM-7C showed a declining trend in relation to both water level and date (Table 5-12). A similar trend for RAM-7G is also shown for pH. The pH in RAM-7C declined from an initial peak of about 11 to about 10.3 at the end of the year. The declining trend for RAM-7G is less apparent from a qualitative examination of the data.

The analysis of RAM-7A data shows a potential direct relationship between specific conductance and potassium concentrations. As potassium is a major cation in retort leachate waters, such an association is not unexpected. Both constituents declined during November and December in RAM-7A.

Table 5-12. Statistically significant slopes identified from regression analysis of RAM-7 monitoring data.

Well	Dependent Variable	Independent Variable	Estimated Slope
RAM-7A	ec	K	19.36
RAM-7B	K	WL	5.12
	K	Date	1.26
RAM-7C	pH	WL	-0.07
	pH	Date	-0.02
RAM-7G	COD	WL	-3.11
	pH	WL	-0.05

B. Water Chemistry - RAM-7

The newly completed RAM-7 well (located in Retort 1) was sampled in September 1984 for basic water chemistry parameters (Table 5-13). The most significant observation from this initial sample collection is that total dissolved solids (TDS) within the retort is relatively low compared to what one may expect based on literature data on retorted shale leachates. This relatively low level of dissolved solids may indicate that very few leaching cycles, perhaps only a single cycle, will be needed to acceptably reduce concentrations within the retort.

Water quality within the retort is quite variable from top (RAM-7A) to bottom (RAM-7G). The pH varies from over 12 at the top of the retort to about 8 at the bottom. This trend is shown by the character of the alkalinity system at various locations within the retort. RAM-7A water is dominated by hydroxide (OH) ions with a fair concentration of carbonate (CO_3) and essentially no bicarbonate (HCO_3). This makeup reverses near the bottom of the retort where bicarbonate ions dominate alkalinity.

The spatial variation in the alkalinity system is probably related to mineralogical changes occurring during retorting and, to a lesser extent, to varying leaching history. The upper sections of the retort (to below the C-zone completion) were exposed to very high temperatures with the passage of the flame front during retorting and have had less opportunity for leaching than the bottom of the retort which has been flooded continuously since the fall of 1982. Also, during retort operation, the flame front did not go all the way to the bottom of the retort. Thus the rubble was not burned like that in the upper levels of Retort 1.

Most of the major cations (Ca, Mg, Na, and K) show some concentration variability among the four samples collected in Retort 1. Calcium (Ca) concentrations decrease slightly toward the bottom of the retort, while potassium concentrations increase somewhat. Sodium (Na) concentrations are fairly constant. The magnesium (Mg) concentration is very low near the top of the retort, and increases to about 19 mg/l at the bottom. It is unclear

Table 5-13. Means of 1984 water quality data for RAM-7 wells. (Units are micromhos per cm for ec, standard units for pH and milligrams per liter for other constituents).

CONSTITUENT	RAM-7A	RAM-7B	RAM-7C	RAM-7G
pH	12.4	11.1	10.0	8.4
ec	11,298	6,912	6,420	6,013
Ca	412	462	474	351
Mg	7	4	11	19
Na	623	661	625	622
K	626	893	834	828
HCO_3	<5	<9	<14	63
CO_3	174	48	35	<4
OH	664	38	<2	<0.5
SO_4	1,039	3,390	3,443	3,248
Cl	31	40	37	40
TDS	3,655	5,628	5,500	5,193
Alk	2,256	223	90	80
NH_3	4.2	4.8	3.9	5.5
F	0.5	1.9	1.8	2.8
Sulfide	0.3	3.0	2.7	3.0
SCN	<2	<1	<1	<1
DOC	15	9	11	30
B	0.2	1.7	1.9	2.1
Li	1.0	1.4	1.4	1.4
Mo	0.3	0.9	0.7	0.2

*Measuremnet probably affected by pH; high pH results in spuriously high ec measurement.

whether these trends are related to retorting history or to the influence of groundwater inflow to the retort. Sulfate (SO_4) concentrations are relatively low, averaging 1,039 mg/l at the top of the retort (RAM-7A) and are over 3,000 mg/l in the rest of the retort. This pattern may be related to that of magnesium and potassium which have the same increasing trend or to the changes in the pH/alkalinity system which changes dramatically from top to bottom of Retort 1.

Chloride (Cl) concentrations increase slightly from top to bottom of the retort. Chloride concentrations are appreciably greater in the collection drift (over 80 mg/l) than in the retort (30-40 mg/l). The reason for this is unknown since the area groundwater typically has low chloride concentrations.

Ammonia (NH_3) and sulfide concentrations are relatively consistent within the retort but increase near the bottom of the retort. Sulfide concentrations greater than 2 mg/l have been observed in the collection drift. Thiocyanate (SCN) was only observed in measurable concentrations (3 mg/l) in one sample from RAM-7A.

Fluoride (F) concentrations increase from top to bottom of the retort. This trend may be related to calcium concentrations which may control fluoride solubility.

The trace constituents sampled (boron (B), lithium (Li) and molybdenum (Mo)) tended to show the lowest concentrations near the top of the retort (RAM-7A). Molybdenum declines at the bottom of the retort (RAM-7G). In addition, single samples in November 1984 from the RAM-7 wells were analyzed for 14 trace metals: iron, aluminum, arsenic, beryllium, chromium, copper, lead, manganese, mercury, nickel, selenium, strontium, vanadium and zinc. Most observations were less than the analytical detection limit. Measurable concentrations (in mg/l) were as follows:

	RAM-7A	RAM-7B	RAM-7C	RAM-7G
aluminum	--	--	0.4	--
iron	--	--	--	0.06
manganese	--	--	--	0.66
strontium	21.0	9.9	9.6	8.8
zinc	0.82	--	--	--

With a few exceptions, as noted below, the composition and concentrations of basic water quality parameters in Retort 1 were fairly stable during the September through October 1984 period. This is shown in the total dissolved solids (TDS) concentrations which exhibited a narrow range in each RAM-7 well:

Well	N	TDS Range (mg/l)	TDS Mean (mg/l)
RAM-7A	4	3510-4080	3655
RAM-7B	4	5580-5730	5628
RAM-7C	4	5470-5530	5500
RAM-7G	4	5080-5350	5193

In RAM-7A and 7G, TDS concentrations declined slightly after the initial samples, which exhibited the maximum concentrations observed at these locations.

In RAM-7A, calcium and sulfate ion concentrations decreased somewhat between September to the end of 1984 while other major inorganic ions were relatively stable. The magnesium ion concentration was 28 mg/l in the November sample and <0.1 mg/l in other samples collected. This November peak in magnesium concentration was also observed in RAM-7B and -7C and may represent a transient influence of ambient groundwater which has appreciably greater magnesium concentrations than observed within the retort.

In RAM-7A, alkalinity, ammonia, and fluoride concentrations were fairly stable throughout the report period, while sulfide and dissolved organic carbon (DOC) were lower in most recent samples. The trace elements

routinely monitored (boron, lithium and molybdenum) were relatively stable or exhibited slight decreasing trends during the report period.

With the exception of the above-noted pattern of magnesium concentrations, concentrations of the basic water quality parameters monitored in RAM-7B were stable through the report period. Sulfide and DOC concentrations may exhibit a slight decreasing trend. These same trends are also evident in RAM-7C, but the major inorganic ions and TDS showed no trends during the report period.

RAM-7G exhibited what may be decreasing trends in the concentrations of calcium, bicarbonate (and alkalinity), chloride, lithium and molybdenum ions. DOC was somewhat reduced in the most recent samples.

Mean dissolved organic carbon (DOC) ranged from 9 to 15 mg/l in the upper three sampling levels in the retort, increasing to a mean of 30 mg/l in the RAM-7G. This is the expected trend since the flame front did not pass through the bottom of the retort. Trace organic (priority pollutant) samples were collected from RAM-7B and -7G in September 1984 and from all RAM-7 wells in November 1984. These data, with results of earlier analysis of samples from the collection drift, are listed in Table 5-14. Of the 87 organic priority pollutants, only a very few are detectable in these samples. Only one compound, benzene, was measurable at 12 ppb in the RAM-7B sample in September. Similarly, only benzene was detected at low concentrations in RAM-7A, -7B, and -7C in November. Five trace organic compounds were found in the RAM-7G samples, including benzene at 38 ppm in September and 51 ppb in November. Compounds observed at less than 10 ppb are not listed here because of analytical errors in this concentration range. Thus the pattern of trace organics is the same as that observed for DOC (and COD as measured on-site). This result supports the earlier decision not to recirculate water from the bottom to top of the retort. That procedure would act to redistribute these trace organics throughout the retort.

These recent trace organic results are generally comparable to the types of compounds and concentrations observed in the earlier samples collected.

Table 5-14. Results of trace organic (priority pollutants) analyses of RAM-7 and collection drift samples. Units are parts per billion (micrograms per liter); ND indicates compound not detected.

	COLLECTION DRIFT SAMPLES				RETORT 1 Sept. 1984		RETORT 1 Nov. 1984			
	Nov. 1982	June 1983	Sept. 1983	May 1984	RAM-7B	RAM-7G	RAM-7A	RAM-7B	RAM-7C	RAM-7G
Acid Compounds:										
2, 4-Dimethylphenol	92	25	ND	ND	ND	170	ND	ND	ND	ND
Phenol	95	ND	69	13	ND	ND	ND	ND	ND	ND
Base/Neutral Compounds:										
Naphthalene	ND	15	ND	ND	ND	20	ND	ND	ND	18
2, 6-Dinitrotoluene	ND	ND	ND	8.8	ND	ND	ND	ND	ND	ND
Di-N-Butylphthalate	ND	ND	ND	7.4(1)	ND	ND	ND	ND	ND	ND
Nitrobenzene	ND	ND	ND	54	ND	26	ND	ND	ND	ND
Volatile Compounds:										
Benzene	30	87	63	52	12	38	28	11	21	51
Toluene	29	38	38	38	ND	15	ND	ND	ND	20
Ethylbenzene	ND	10	ND	8.4	ND	ND	ND	ND	ND	ND
m-Xylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	11
o- or p-Xylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	13
Methylethylketone	ND	ND	ND	ND	ND	ND	15	ND	ND	ND

(1) This may reflect contact with plastics during sampling; this compound was only one observed in mine water (at 7 ppb) and was not found in other samples when only glass containers were used.

Thus, as reported in the September 1983 abandonment plan proposal, there do not appear to be any compounds present in retort leachate at levels to individually produce significant toxic effects.

Other trace organics measured using GC/MS analysis are listed in Table 5-15. Compounds observed at less than 10 ppb are not reported. Most of the compounds observed in the RAM-7A sample were pyridines, quinolines, phenols, organic acids and hydrocarbons. The presence of basic nitrogen compounds and somewhat higher concentrations distinguishes this sample from those collected away from the retort (see later discussion). RAM-7B contained low concentrations of hydrocarbons, phenols, pyridines and organic acids while RAM-7C had low concentrations of hydrocarbons, organic acids and cresols. As expected, RAM-7G contained the most organic compounds, including pyridines, quinolines, indoles, phenols and a few cycloparafins and aromatic hydrocarbons. Phenols and nitrogen compounds were observed at concentrations of 100 to 1,000 ppb.

4. Near-Retort Water Quality Evaluation

As outlined for the RAM-7 well, monitoring near the retort includes on-site analyses as well as the more detailed laboratory chemistry analyses. Sampling was initiated in May 1984 with the initial flooding of the retort system and continue as per the approved monitoring scope of work.

A. On Site Analysis

The following summarizes the results of on-site analyses for each of the RAM well completion zones. For example, all A-groove completions are considered as a group, initially near the retort (wells RAM-5, -2 and -6) followed by an assessment of observations more distant from Retort 1 (wells RAM-3 and -4).

A-Groove. Specific conductance (ec) in all of the near-retort RAM wells (RAM-5, -2 and -6) was greatest in the initial samples collected. Observed ec then declined rapidly to equilibrium levels observed at the end of 1984.

Table 5-15. Trace Organics in Retort 1, Sampled November 1984. Units are parts per billion.

	RAM-7A	RAM-7B	RAM-7C	RAM-7G
Volatiles				
acetone	10-100	--	--	--
methylethyl ketone	27	--	--	--
benzene	28	11	21	51
toluene	--	--	--	20
ethylbenzene	--	--	--	5
m- xylene	--	--	--	11
o - or p- xylene	--	--	--	13
possible cyclic ketones	--	--	--	10-100
a methyl styrene	--	--	--	10-100
a C9 alklbenzene	--	--	--	10-100
trimethylpyridine	--	--	--	10-100
Base/Neutral/Acid				
a dimethylpyridine	--	--	--	10-100
a trimethylpyridine	10-100	--	--	100-1000
a trimethylpyridine	10-100	--	--	--
a C3-sub. pyridine plus a C3 sub. pyrrole	--	--	--	10-100
branched undecane plus C3 and C4 sub. benzenes	10-100	--	--	--
a trimethylbenzene plus C3 sub. pyrrole	--	--	--	10-100
a C10 olefin or cycloparafin	10-100	--	--	--
a trimethyl pyridine	--	--	--	10-100
a trimethylpyridine and C3 and C4 sub. benzenes	10-100	--	--	--
ethyldimethyl pyridine	10-100	--	--	100-1000
C4 sub. pyridine	--	10-100	--	100-1000
a dimethylphenol	--	--	--	10-100

Table 5-15. Continued

	RAM-7A	RAM-7B	RAM-7C	RAM-7G
Base/Neutral/Acid				
2,4 - dimethylphenol	10	--	10	--
a trimethylpyridine and C4 sub. benzene	10-100	--	--	--
a trimethylpyridine and probable N compound	--	--	--	100-1000
C5 sub. pyridine	10-100	--	--	--
a dimethylphenol	10-100	--	10-100	100-1000
Naphthahene	--	--	--	18
a dimethylphenol and C5 sub. pyridine	--	--	--	100-1000
a trimethylphenol	10-1000	--	10-100	100-1000
Possible C5 sub. pyridine and C4 sub. benzene	10-100	--	--	--
an ethylmethylphenol	--	--	--	10-100
a trimethylphenol	--	--	--	100-1000
a methyltetrahydro quinoline	10-100	--	--	--
a methylquinoline	--	--	--	100-1000
C-4 sub. phenol	--	--	--	10-100
a C 11 olefin or cycloparafin and C4 - sub. phenol	--	--	--	10-100
a dimethyl quinoline	10-100	--	--	100-1000
a dimethyl indole	--	--	--	10-100
a trimethyl indole	--	--	--	10-100
dodecanoic acid	10-100	--	--	--
N - compound	--	--	--	10-100
tetradecanoic acid	10-100	--	--	--
Methyl quinoline oxide	--	--	--	10-100

Initial observations in RAM-5 and -6 (and in RAM -3) were about 2,200-2,500 micromhos per cm and have then declined to about 1,800 micromhos per cm in each of these three wells. Specific conductance in RAM-2A, located to the south of Retort 1, was initially over 3,800 micromhos per cm and then declined to about 2,700 near the end of October and remained there through December. Thus in RAM-2A the same pattern was observed as in other near-retort wells but with higher ec levels, possibly indicating a more direct interaction with the retort than exists for the other near-retort wells. These observations were relatively low compared to the over 10,000 micromhos per cm observed in RAM-7A in October. Specific conductance in RAM-4A which is located about 400 feet north east of Retort 1, has been relatively stable in the about 1,650 to 1,750 range, with one observation of 1,550 micromhos in August. Ambient conditions in the mine-retort area appear to be in the 1,500-2,000 micromhos per cm range.

The temporal pattern observed for specific conductance is also evident for potassium (K) concentrations in the near retort wells. Initial observations in RAM-2A, -5A and -6A were 160, 12 and 25 mg/l, respectively, declining to about 1 to 2 mg/l in RAM-5A and -6A in July and continuing at that concentration through the end of 1984. In that time frame, K concentrations in RAM-2A have declined to 8-10 mg/l and somewhat lower near the end of 1984. All observations in RAM-7A have been greater than 620 mg/l potassium and averaged over 750 mg/l during the report period. Observations in RAM-3A and -4A have been at ambient concentrations of less than 2 mg/l.

The pH in A-groove wells was very stable during the report period. RAM-2 through -6 wells have been 7.1 to 7.4, except for a single observation of 7.8 in RAM-6A. The upper aquifer mean pH is 7.5 (for the 1984-82 period). Observations of pH in RAM-7A have all been between 12.4 and 12.6.

Temperatures in the A-groove wells were fairly steady for a given location throughout the report period, although groundwater temperatures may be declining somewhat toward the end of 1984. Temperatures were, however, quite variable horizontally within the A-groove. The mean 1984 temperature in RAM-7A in Retort was 30.6^{o}C. The near-retort wells RAM-5A, -6A and -2A

averaged 14.0, 13.7 and 16.7°C respectively. These temperature data also support the conclusion of stronger interaction between the retort and RAM-2A than between the retort and other near-retort wells. In wells more distant from the retort, temperatures were near 12°C.

Ammonia concentrations in the retort (RAM-7A) were in the 5 to 10 mg/l range during the report period. With the exception of RAM-2A, concentrations in other RAM wells have been less than 1 mg/l since the wells were completed. Concentrations up to 3 mg/l were observed in late June in RAM-2A. These concentrations declined rapidly to ambient conditions, with reported concentrations either 1 or less than 1 mg/l.

Sulfide concentrations both in the A-groove in Retort 1 and in surrounding RAM wells were all less than the analytical detection limit of 1 mg/l. This indicates that this parameter may not be a useful on-site analysis.

Similarly, there is little observed difference between fluoride concentrations in RAM-7A and in A-groove completions near Retort 1. All observations, at all wells, including in Retort 1, have been in the 0.4 to 1.4 mg/l range. By comparison, the mean fluoride concentration in the upper aquifer (1974-1982) is 1.1 mg/l. These data indicate little use for this parameter as a retort impact measure.

The phenol concentration in the retort (RAM-7A) was unchanged at 1 mg/l through November. In December concentrations of 0.2 to 0.3 mg/l were observed. Observed concentrations in near-retort wells have been typically 0.1 mg/l, the analytical detection limit, or less. All observations in RAM-4A have been <0.1 mg/l.

The other measure of organics measured on-site is chemical oxygen demand (COD). COD concentrations in RAM-7A have been generally in the 40 to 60 mg/l range, averaging 51.8 mg/l, including a spuriously high of 145 mg/l. Observations in RAM-3A and -4A have been mostly in the 10-25 mg/l range, averaging 15.4 and 17.1 mg/l respectively. COD concentrations somewhat greater than this have been observed occasionally in near-retort wells

(RAM-5A, -2A and -6A). Concentrations in RAM-5A and -6A have been fairly steady at about 20 mg/l (averaging 19.9 and 20.3 mg/l respectively during 1984), with occasional higher observations but no clear trends. Observations in the 15 to 25 mg/l range probably represent ambient conditions. Concentrations in RAM-2A were initially greater than 30 mg/l (with maximum observations of 52 mg/l). Observations from October through the end of 1984, were in ambient range as noted above. These data, with the observations for phenol, indicate little effect of the retort on organic concentrations in the A-groove.

B-Groove. In Retort 1 adjacent to the B-groove (RAM-7B), specific conductance (ec) has ranged from 5,331 to 6,703 micromhos per cm during the 1984 sampling period, with most observations over 6,000. Initial observations in RAM-5B, north of Retort 1, were slightly over 4,000 micromhos per cm in June followed by a decline to about 3,200 in early July. After July, ec in RAM-5B increased to about 3,500-4,000 through the end of 1984, averaging 3,556 for the report period. RAM-2B ec was about 2,000 micromhos per cm in June and has increased and apparently stabilized at around 3,000 micromhos per cm. There were transient peaks of about 3,800 micromhos per cm in August and in November but the early increasing trend was not evident at the end of 1984. The conductance in RAM-6B, east of Retort 1, has been relatively stable at 2,200 to 2,500 micromhos per cm through the 1984 report period. Thus the near-retort B-groove wells have stabilized at ec levels about 40 to 60 percent of levels in RAM-7B.

Specific conductance in RAM-3B was initially (June and July) about 2,400 to 2,500 micromhos per cm, declining in year-end samples to around 2,000. Observations in RAM-4B have been mostly in the 1,500 to 1,700 micromhos per cm range, averaging 1,569 for the report period. Ambient levels in the B-groove are 1,500 to 2,500 micromhos per cm in the vicinity of the mine and retort.

Potassium (K) concentrations in RAM-7B ranged from 670 to 900 mg/l, averaging 779 mg/l in 1984. Concentrations in near-retort wells, RAM-5B and -2B in recent samples have been in the 3 to 6 mg/l range. In RAM-5B,

initial samples showed elevated K concentrations, up to 11 mg/l. These concentrations have declined, reaching and remaining at about 4 to 6 mg/l since mid-July. RAM-2B exhibited one observation (in early July) of 36 mg/l potassium, but most observations have been about 3 mg/l. The July analysis (36 mg/l) may be in error. The last observation in 1984 in RAM-2B was 8 mg/l K, but, from more recent data, this appears to be a transient peak or analytical error.

Potassium concentrations in RAM-6B were 1 to 2 mg/l through mid-October when concentrations increased to up to 4 mg/l. In late November 1984, potassium concentrations increased appreciably, to 20 mg/l in one sample in December. This increasing trend has continued, with January and February samples over 30 mg/l potassium, indicating a likely influence from Retort 1 at this location to the east of Retort 1. These observed concentrations are however only about 4 to 5 percent of the potassium concentrations observed in Retort 1 (RAM-7B). Potassium concentrations in the upper aquifer (1974-1983) have averaged 1.4 mg/l, ranging up to 8.5 mg/l. Observations in RAM-3B and -4B have all been 2 mg/l or less.

RAM-7B pH has averaged about 11.4 during the report period. Most pH observations in near-retort wells have been in the 7.1 to 7.6 range, which is about ambient for the upper aquifer.

Water temperatures in RAM-7B were steady at 30 to 32.1^{o}C in 1984 samples. Mean 1984 temperatures in RAM-5B, -6B and -2B were 19.7, 15.9 and 17.4^{o}C respectively. Water temperatures may be declining slowly in these near-retort wells, as well as in RAM-3B and -4B which exhibited mean temperatures of 14.0 and 12.5^{o}C, respectively, during 1984.

Ammonia concentrations in near-retort B-groove wells have mostly been less than 1 mg/l with a few observations at or near the detection limit of 1 mg/l. This has been the result of all samples collected in RAM-3B and 4-B. A few samples from RAM-5B and -2B have exhibited ammonia concentrations up to 1.6 mg/l. These are well below recent concentrations in RAM-7B (Retort 1), which ranged from 5.4 to 8.8 mg/l during the report period. RAM-6B

exhibited a rise in ammonia concentration to over 2 mg/l in December 1984 and January 1985, related to the retort effects noted for potassium.

All sulfide observations outside of the retort (RAM-7B) have been to be less than 1 mg/l, the analytical detection limit. RAM-7B has exhibited sulfide concentrations up to 5 mg/l, averaging 3.1 mg/l for 1984.

Fluoride (F) concentrations were fairly stable throughout the report period in all the B-groove wells, RAM-2B through -6B. Concentrations ranged from 0.7 to 2.1 mg/l with averages for individual wells being 1.5 mg/l F or less. Fluoride concentrations in the retort (RAM-7B) ranged from 2.0 to 3.6 mg/l and averaged 3.1 mg/l during the 1984 report period. No clear trends are evident, although concentrations may have increased slightly since the beginning of the sampling program.

All phenols observations in RAM-7B (Retort 1) have been 1 mg/l. Virtually all observations east of the retort (RAM-6B, -3B and -4B) have been less than 0.1 mg/l, the analytical detection limit. One upscale of 2.1 mg/l phenols in RAM-6B probably is not accurate. Phenols in RAM-5B have usually been 0.1 mg/l with two samples at 0.2 mg/l. All phenols observations in RAM-2B have been less than or equal to 0.1 mg/l.

COD concentrations in RAM-7B ranged from 28 to 45 mg/l during 1984, averaging 35.5 mg/l. Average 1984 COD concentrations in near-retort wells, RAM-5B, -6B, -2B, were 23.4, 20.1 and 18.1 respectively and were somewhat variable during the report period but with no clears trends. All COD observations in RAM-3B and -4B have been less than 21 mg/l, again with no clear trends.

C-Zone. Specific conductance (ec) in near-retort monitor wells (RAM-5C, -6C and -2C) have been relatively stable and probably represent ambient conditions at these locations. The ec in RAM-5C, -6C and -2C during 1984 averaged 1786, 1485 and 1629 micromhos per cm, respectively. Each of these wells has exhibited single upscale values of over 2,400 micromhos but these were probably spurious results as there is no other indication of influence

from the retorts. Observations in RAM-3C and -4C are typically below 1,600 micromhos per cm. All observations in RAM-7C have been greater than 5,300 micromhos per cm.

Potassium concentrations in non-retort RAM wells have typically been less than 3 mg/l. Upscale concentrations which could indicate retort interactions have not been observed. A single observation of 11 mg/l K in RAM-6C in November is probably an error. Retort potassium concentrations (RAM-7C) have all been greater than 660 mg/l and averaged 738 mg/l during the 1984 report period.

The pH in Retort 1 opposite the C-zone (RAM-7C) was greater than 10 during 1984. The pH in near-retort wells (RAM-5C, -6C and -2C) has been mostly in the 7.5 to 7.9 range with RAM-6C, east of Retort 1, exhibiting somewhat greater pH (with a maximum of 8.1) than the other two wells. Water pH readings up to 8.0 and 8.1 have been observed in RAM-3C and -4C, respectively. No trends were apparent for the 1984 sampling period.

Temperatures within Retort 1 (RAM-7C) ranged from 28 to 32°C and averaged 30.6°C during the 1984 sampling period. Mean 1984 temperatures in RAM-5C, -6C and -2C were 17.7, 15.8 and 19.6°C, Respectively. This is the similar spatial pattern of temperature observed in the A- and B-groove completions near Retort 1, with the RAM-6 completion being cooler than the other two wells. There were no clear trends, although temperatures in RAM-6C, to the east of Retort 1, may be declining slowly. Water temperatures in RAM-3C and -4C were similar, averaging 14.2 and 13.2°C, respectively, during 1984.

All ammonia observations in RAM-2C through -6C have been less than 1 mg/l as compared to in-retort concentrations which ranged from 4.7 to 8.0 mg/l during 1984.

Observations of sulfide concentrations in near-retort wells (RAM-5C, -6C and -2C) have all been less than 1 mg/l. In-retort observations range up to 5 mg/l but averaged 1.1 mg/l in 1984 as many observations were less than 1 mg/l. Similar observations of up to 5 mg/l have been recorded for RAM-3C

and a single value of 40 mg/l was exhibited in RAM-4C. These upscale sulfide concentrations have been supported by lab analyses; sulfide concentrations of 29 and 26 mg/l were reported for RAM-3C and -4C, respectively, in September samples. The cause of these relatively high concentrations is not known, but from examination of overall water quality in these wells, it does not indicate a direct interaction with the retort. High pre-development sulfide concentrations have been observed for the upper aquifer on and around Tract C-a.

RAM-7C (retort) fluoride concentrations have ranged up to 3.5 mg/l and averaged 2.8 mg/l in 1984 samples. Concentrations in near-retort wells have been less than 2.8 mg/l with no clear trends. Fluoride concentrations in RAM-3C have increased from 1.6 mg/l in June to 2.5 mg/l in December.

Concentrations of phenols in RAM-2C through -6C have been occasionally 0.1 mg/l, the analytical level of detection but have usually been less than 0.1 mg/l. Concentrations in the retort (RAM-7C) have remained constant at 1 mg/l.

Observed COD concentrations in RAM-7C (Retort 1) have all been greater than 20 mg/l and typically greater than 30 mg/l. The average for 1984 samples of RAM-7C was 38.8 mg/l COD. Concentrations in near-retort wells (RAM-5C, -6C and -2C) have been somewhat variable, but no trends are evident. Mean COD in these three wells for 1984 was 16.5, 22.1 and 24.5 mg/l respectively. RAM-3C has exhibited an increasing trend from 15 mg/l in June to over 50 mg/l in the summer and fall samples. Concentrations near the end of 1984 declined to about 30 mg/l. Since a similar increase has not been observed in RAM-6C, which is between RAM-3 and Retort 1, the increase in RAM-3C is probably not related to interconnection with the retort. RAM-4C has also shown some relatively high concentrations (up to 32 mg/l) but with no definite trend and samples collected near the end of 1984 were 20 to 25 mg/l COD.

G-zone. The following compares water quality in the retort and in monitor well RAM-2 at the elevation of the mine's G-level; these are wells RAM-7G and RAM-2G, respectively.

Specific conductance in the retort (RAM-7G) has ranged from 5,202 to 5,979 micromhos per cm in 1984 samples. The initial sample from RAM-2G (May) was 2,200 micromhos per cm. Samples since then have been in the 1,800 to 2,050 range, with a single sample at 1,700 micromhos per cm. No trends are apparent in these data.

Potassium concentrations in RAM-2G have been variable, with several upscale (higher than expected ambient) observations of over 10 mg/l. However, with between-peak observations of 2 to 4 mg/l, no trends are clear and the peak concentrations appear to be transient effects from the retort system. RAM-7G potassium concentrations range from 660 to 820 mg/l.

The pH in the retort (RAM-7G) has ranged up to 9.5 but most observations (September-October) have been 8.8 to 9.2. The initial pH in RAM-2G was 8.1 in May; subsequent samples are in the 7.2 to 7.6 range.

Water temperatures in RAM-7G are comparable to that observed in other RAM-7 completions and averaged 30.5^{o}C in 1984 samples. No trends are apparent in these data. RAM-2G temperatures ranged from 15.7 to 19.6^{o}C, averaging 17.9 during 1984. This is somewhat cooler than in RAM-2C but comparable to other RAM-2 completions.

Ammonia concentrations in RAM-2G have been variable but low, ranging from less than 1 to 2.6 mg/l. The observations near the end of 1984 in this well were at or below 1 mg/l. Ammonia concentrations in RAM-7G ranged from 5.8 to 10.2 mg/l and averaged 8.2 mg/l in 1984 samples. No appreciable influence from the retort is apparent in these data.

Reported sulfide concentrations in RAM-2G are all less than 1 mg/l, the analytical limit of detection. Observations in the retort averaged 2.3 mg/l in 1984 samples are ranged from less than 1 to 5 mg/l.

Fluoride concentrations in RAM-2G in 1984 ranged from 1.7 to 4.1 mg/l and averaged 2.6 mg/l. The highest concentrations were in the initial samples. Observations in the retort (RAM-7G) ranged from 3.6 to 5.7 mg/l during 1984, with no clear trends.

Phenol concentrations in RAM-2G were less than 0.1 mg/l in all samples in 1984. Phenol concentrations in RAM-7G ranged from 0.4 to 1.0 and averaged 0.7 mg/l. With the exception of the initial sample (56 mg/l), COD concentrations in this monitor well have all been in the 10 to 20 mg/l range, averaging 18.4 mg/l in 1984. Concentrations in the retort (RAM-7G) averaged 86.3 mg/l in 1984 samples and ranged from 33 to 180 mg/l. With the exception of one sample, all observations in RAM-2G in 1984 were less than 110 mg/l COD. No influence from the retorts is evident in these organic analyses.

Statistical Analysis. As was described for RAM-7 well data, potential trends and interrelationships were examined by using on-site analysis data to estimate linear regression parameters. The results of this regression analysis for the near-retort wells (RAM-2, -5 and -6) are summarized in Table 5-16.

In the A-Groove wells, the greatest number of significant trends were found for RAM-2A, to the south of Retort 1. Specific conductance, potassium, COD, fluoride and ammonia decreased with rising water level (and also with time for potassium, COD and fluoride concentration). Variation in specific conductance (which generally declined with time during 1984) was positively associated with variations in pH and potassium and COD concentrations.

Significant trends with time and water level in RAM-5A were very small. Although neither constituent showed significant trends in time or with changes in water level, ec and COD exhibited an inverse relationship. Since neither ec nor COD was particularly variable, the meaning of this association is unclear.

Table 5-16. Statistically significant slopes identified from regression analysis of data from near-retort monitor wells (RAM-2, -5, -6).

	RAM-2			RAM-5			RAM-6		
Aquifer Zone	Dependent Variable	Independent Variable	Estimated Slope	Dependent Variable	Independent Variable	Estimated Slope	Dependent Variable	Independent Variable	Estimated Slope
A-Groove	ec	WL	-9.34	K	WL	-0.02	ec	WL	-2.57
	K	WL	-0.87	F	WL	0.002	K	WL	-0.12
	COD	WL	-0.18	pH	WL	0.001	F	WL	0.002
	F	WL	-0.004						
	NH_3	WL	-0.02						
	K	Date	-0.50	F	Date	0.002	K	Date	-0.06
	COD	Date	-0.17	pH	Date	0.002	F	Date	0.002
	F	Date	-0.003						
	ec	K	9.31	ec	COD	-7.63	ec	K	27.42
	ec	COD	23.82				ec	pH	875.52
	ec	pH	2907.9						
	K	COD	1.33						
	F	K	0.004						
B-Groove	F	WL	0.003	F	WL	0.003	pH	WL	0.002
				NH_3	WL	-0.01			
				pH	WL	0.002			
	F	Date	0.003	ec	Date	3.67	K	Date	0.009
	pH	Date	0.007	F	Date	0.003	F	Date	0.003
				NH_3	Date	-0.007	pH	Date	0.002
				pH	Date	0.002			
				F	K	-0.09	ec	pH	-1111.4

Table 5-16. Continued

Aquifer Zone	RAM-2 Dependent Variable	RAM-2 Independent Variable	RAM-2 Estimated Slope	RAM-5 Dependent Variable	RAM-5 Independent Variable	RAM-5 Estimated Slope	RAM-6 Dependent Variable	RAM-6 Independent Variable	RAM-6 Estimated Slope
C-zone	COD	WL	-0.17	pH	WL	0.002			
	pH	WL	0.002						
				ec	K	49.77	ec	K	120.91
							ec	COD	-15.03
							ec	pH	-1438.3
							K	COD	-0.08
							F	K	-0.16
	K	Date	0.01	K	Date	0.02	pH	Date	-0.001
	COD	Date	-0.09	pH	Date	0.001			
	pH	Date	0.001						
G-level	COD	WL	-0.085						
	F	WL	-0.004						
	pH	WL	-0.001						
	K	COD	-0.42						

In RAM-6A, ec and potassium concentration decreased with rising water level and with time (for potassium). Not surprisingly, variations in ec were directly associated with potassium as it was with pH. Fluoride concentrations increased slowly with water levels and over time.

Significant trends in the near-retort B-groove wells were generally small (Table 5-16). The greatest trend slope found for RAM-5B was the increasing trend of ec with time. This trend mostly reflects increases in ec after an initial decline over the first month after sampling was initiated.

Fewer significant trends related to water level and date were found for the near-retort C-zone wells than were observed for B-groove wells. This indicates more stable water quality conditions in the C-zone wells. Several significant associations among the constituents sampled were found for RAM-6C. However, with the generally small range of variation observed at this location, the meaning of the inferred relationship is unclear.

RAM-2G exhibited a decreasing trend in COD, fluoride and pH with rising water levels. Similar results, but with greater slopes, were observed for RAM-7G.

Generally fewer significant trends and interrelationships were observed for RAM-3 and -4 wells than were found in the near-retort monitor wells (Table 5-17). RAM-3A exhibited a decreasing trend in ec with time. With no other significant trends indicated, water quality at this site is very stable. In RAM-3B COD decreased with the rising water levels and over time. The pH and fluoride concentrations increased with the rising water levels in RAM-3B and RAM-3C. Potassium concentration decreased in RAM-3C with the rising water levels.

Few significant trends were found for the RAM-4 wells (Table 5-17). The pH increased slowly with rising water levels and with time in RAM-4A. Fluoride concentration increased over time in RAM-4B and decreased in RAM-4C.

Table 5-17. Statistically significant slopes identified from regression analysis of data from RAM-3 and RAM-4.

	RAM-3			RAM-4		
Aquifer Zone	Dependent Variable	Independent Variable	Estimated Slope	Dependent Variable	Independent Variable	Estimated Slope
A-Groove				pH	WL	0.002
	K	COD	-0.34			
	ec	Date	-3.90	pH	Date	0.002
B-Groove	COD	WL	-0.09			
	F	WL	0.01			
	pH	WL	0.004			
	COD	Date	-0.07	F	Date	0.005
	pH	Date	0.003			
C-Zone	K	WL	-0.02			
	F	WL	0.01			
	pH	WL	0.01			
	pH	Date	0.004	F	Date	-0.004
	F	K	-0.35			

B. Water Quality - RAM Wells

Water quality has been sampled in RAM-2 through 6 wells several times since the wells were completed in May 1984. The initial samples were collected as the system water levels rose and filled the various completion zones. Wells were bailed to clean out, to the extent possible, drilling fluids, solids from completion activities, etc. Listings of data from laboratory analyses of water quality are provided in Appendix 5-3.1.

A general, qualitative comparison of the water quality observed (through October 1984) in RAM-2 through -7 with ambient water quality was presented in a previous report to the BLM/OSPO (December 1984). Analysis of samples collected in November and December 1984 has not greatly changed the conclusions of this earlier evaluation which are summarized below.

The results of this general evaluation for the four RAM-7 wells showed that nearly all major inorganic ions are at concentrations greater than the upper aquifer ambient P95 concentrations. Magnesium (Mg) and bicarbonate (HCO_3) are exceptions as they are found in concentrations less than the ambient mean in the retort (RAM-7 wells). Dissolved organic carbon (DOC) concentrations in the retort are between the ambient mean and P95 concentrations. This indicates that interaction between outlying RAM wells and the retort would be accompanied by high levels of most if not all of the major inorganic ions.

The results of data collected through October showed interaction with the retort may be evident in RAM-2A, -2B and -5B. December sampling also showed a similar interaction between the retort and RAM-6B, with increases in concentrations of TDS and several major and minor ions. On-site analyses also support this conclusion for RAM-6B. Several wells exhibit relatively high concentrations of magnesium (Mg), calcium (Ca) and sulfate (SO_4) ions. The magnesium and sulfate probably come from leaching of fractured raw shale around the retort and mine area. Leachate from raw shale the Tract C-a mine is saline and dominated by magnesium and sulfate ions. The explanation for the calcium data is less certain.

To make a closer examination of RAM-2A, -2B, -5B and -6B, the percentage change between these locations and the associated level in the retort (i.e., RAM-7A or -7B) was calculated (Table 5-18) using the December 1984 data. The alkalainity system (HCO_3, CO_3, OH) is not included in the table as this system undergoes a complete reversal from dominance of hydroxide in the retort to a dominance of bicarbonate in the aquifer zones outside the retort.

The results shown in Table 5-18 are, overall, very similar to results reported to the BLM/OSPO using initial (September) samples. In the December analysis, calcium (Ca) was less reduced (26.4%) in RAM-2A vs. the retort than was reported for September samples (51.9%) and sulfate and boron concentrations in December were greater in RAM-2A than in the retort. The results for B-groove wells are very close to the earlier analysis of September data. DOC patterns were changed due mostly to reduced DOC concentration in all wells in December relative to September.

The data in Table 5-18 show that concentrations of major inorganic ions for the most part decrease from about 30 to 70 percent from the retort to the RAM wells. This is a much greater reduction than would be expected for dilution and dispersion of continual flows away from the retort. Exceptions to this pattern are:

- magnesium concentrations which are very low in the retort and around 200 mg/l or greater in the near-retort monitor wells (Magnesium concentrations in the upper aquifer (1974-1982) averaged 76.2 mg/l, ranging from 3.5 to 221 mg/l. Also, the new RAM wells probably exposed fresh mineral deposits, leading to greater than ambient concentrations in these wells).

- sulfate and fluoride concentrations in RAM-2A which are comparable to or greater than concentrations in the retort (RAM-7A)

- potassium concentrations in monitor wells are negligible relative to in-retort concentrations

Table 5-18. Percentage change (1) in water quality from Retort 1 to RAM-2A, -2B, -5B and -6B, December 1984

Constituent	Retort 1		RAM-2A		RAM-2B		RAM-5B		RAM-6B	
	RAM-7A, December mg/l	RAM-7B, December mg/l	December mg/l	Relative to RAM-7A %	December mg/l	Relative to RAM-7B %	December mg/l	Relative to RAM-7B %	December mg/l	Relative to RAM-7B %
Ca	390	463	287	26.4%	286	38.2%	323	30.2%	137	70.4
Mg	0.7	0.1	186	-264.7	257	-2569.0	295	-2949.0	192	-1919.0
Na	630	690	198	68.6	274	60.3	386	44.1	226	67.2
K	610	880	9.1	98.5	2.9	99.7	4.7	99.5	9.2	99.0
SO_4	990	3340	1430	-44.4	1870	44.0	2340	29.9	1120	66.5
Cl	31.6	36.1	16.3	48.4	11.1	69.3	15.3	57.6	17.0	52.9
TDS	3520	5580	2530	28.1	3180	43.0	3840	31.2	2110	62.2
NH_3	5.39	5.09	0.30	94.4	0.29	94.3	0.27	94.7	0.35	93.1
F	0.5	1.9	0.4	20.0	0.8	57.9	0.9	52.6	0.9	52.6
Sulfide	0.07	1.71	<.02	71.4	<.02	98.8	0.02	98.8	<.02	98.8
DOC	9	3	5	44.4	4	-33.3	<2	33.3	2	33.3
B	0.18	1.79	0.28	-55.6	0.22	87.7	0.18	89.9	0.36	80.0
Li	0.87	1.33	0.24	72.4	0.25	81.2	0.31	76.7	0.25	81.2
Mo	0.3	1.0	0.3	0.0	0.5	50.0	0.3	70.0	0.1	90.0

(1) Percent change relative to RAM-7; e.g.: RAM-2A relative to RAM-7A:

$$\frac{(7A \text{ concentration}) - (2A \text{ concentration})}{7A \text{ concentration}} \times 100$$

Also dissolved organic carbon (DOC) concentration in December in RAM-2B, -5B and -6B were comparable to that observed in RAM-7B, although because of the low RAM-7B DOC concentration (3 mg/l) the percentage difference is 33 percent.

More reactive constituents (ammonia, sulfides and thiocyanate) are relatively high in the retort and negligible in the monitor wells. Thiocyanate (SCN) was not measurable in any of the monitor wells considered here, and thus was not evaluated.

The trace elements (boron, lithium and molybdenum) were typically greatly (>70 percent) reduced in B-groove monitor wells relative to the retort. Boron concentrations in RAM-2A in December were greater than in the retort and molybdenum concentrations were equal. Lithium in the A-groove showed a decline similar to that observed for B-groove wells.

In November 1984, additional trace metals were sampled at selected locations (RAM-2A, -2B, -4B and -5B). Only four of the 14 trace metals exceeded analytical limits (mg/l):

					Upper Aquifer Pre-1980	
	RAM-2A	RAM-2B	RAM-4B	RAM-5B	Mean	P95
iron	1.65	1.40	.48	1.52	3.38	15.0
manganese	0.30	1.40	.62	3.30	.16	.44
strontium	12.0	11.9	8.3	11.1	3.0	9.7
zinc	1.20	3.90	0.02	0.49	.82	1.9

The iron, manganese and zinc concentrations observed were generally greater than found in Retort 1. Manganese, strongium and zinc (in RAM-2) were also greater than ambient upper aquifer means. The strontium concentrations were generally comparable to concentrations observed in the retort. Thus these trace metals may have little utility for detecting retort impacts.

Trace organics were sampled in selected monitor wells in November 1984. RAM-2A, -2B and -5B were sampled because other chemical monitoring had indicated some effects from the retort flooding at these locations. RAM-4B was sampled as a control, since no retort effects were apparent at this location.

Only two priority pollutants were quantified (in ppb) at these sites:

	RAM-2A	RAM-2B	RAM-5B	RAM-4B
Benzene	23	18	24	--
di-N-butylphthalate	11	--	---	18

The di-N-butylphthalate is probably the result of contact of the sample with plastics at some point in the sampling/analysis procedures. This compound was not observed in samples collected from RAM-7 wells in the retort.

The benzene concentrations observed are comparable to concentrations observed in the upper levels of Retort 1 (Table 5-14). This material is part of the light oil fraction produced during MIS retorting operations.

The GC/MS analysis showed very few trace organic compounds above the 10 ppb level of analysis (Table 5-19). Qualitatively, RAM-2A contained low concentrations (<10 ppb) of hydrocarbons, phenols and organic acids. Several phthalates were found at low concentrations plus 10 to 100 ppb of diisobutyl phthalate and 100 to 10,000 ppb of a butyl phthalate ester. These phthalates may result from contact with plastics in sampling or analysis. The sample from RAM-4B was similar to that from RAM-2A. RAM-2B exhibited low concentrations of several paraffins and cycloparaffins with a few chlorinated cycloparaffins at 10 to 1,000 ppb. RAM-5B had low concentrations of paraffins, cycloparaffins, aromatics and organic acids.

Table 5-19. Trace organics in wells near Retort 1, November 1984. Units are parts per billion.

	RAM-2A	RAM-2B	RAM-5B	RAM-4B
Volatiles				
Benzene	23	18	24	--
di-isobutylphthalate	10-100	--	--	10-1000
di-N-butyl phthalate	11	--	--	18
a phthalate ester	100-1000	--	--	100-1000
a trimethylcyclopentane	10-100	--	--	--
dichlorobutane and pentachloroethane	--	10-100	--	--
a dichlorocyclohexane	--	100-1000	--	--

5.4 SUMMARY

The hydrology monitoring program collects information for several needs:

- Stipulations of the lease and conditions of approval from the OSO
- Engineering design input for mine and water handling systems
- Evaluation of the need for environmental mitigative measures
- Permit requirements

The program includes monitoring at numerous installations, including stream gaging stations, springs and seeps, alluvial and deep aquifer wells, surface impoundments, surface discharges and reinjection system. The natural hydrologic and hydrogeologic environment as well as facilities associated with tract development have been monitored.

During 1984, the hydrology monitoring program focused on three major areas at Tract C-a:

- Dewatering/Reinjection/Discharge Program
- MIS Modular Development Area
- MIS Retort Abandonment Program

Hydrology monitoring stations have been classified as follows:

- Type I - control stations not expected to be influenced by a given set of development activities

- o Type II - expected to exhibit direct, short-term impacts, should impacts result from development; such stations are located generally close to and downgradient in near-field area relative to development

- o Type II - expected to exhibit indirect or long-term impacts; should impacts result from development; such stations are located downgradient and relatively distant from development in far-field areas.

Grouping stations allows for spatial as well as temporal comparison of water quality and physical parameters. Thus "pre and post" development levels and the "control vs. potentially affected" areas can be compared.

A. Dewatering/Reinjection/Discharge

The upper aquifer near the MIS area was dewatered during suspension operations and dewatering continued until initiation of retort abandonment activities in June 1984. With this system not operating during the remainder of 1984, the cone-of-depression has filled and groundwater levels have returned to near baseline levels.

Mine water production fluctuated between 1,359 gpm and 1,514 gpm from January through mid-may 1984. Field measurements of mine water collected from the composite reinjection were similar to 1983 measurements. Conductivity ranged from 1,380 to 1,930 umhos/cm and pH ranged from 7.1 to 8.2. Water chemistry constituents for 1984 were also very similar to previous years for composite reinjection, indicating stable water quality conditions over time.

Mean depth to water in the upper aquifer remains greater in the near-field area, biased by the dewatering operations during the first half of 1984. Groundwater temperature was greater in the near-field area, while conductivity and pH were highest in the far-field area.

A spatial comparison of water chemistry parameters between control, near-field and far-field areas shows conductivity, TDS, alkalinity, magnesium, bicarbonate and sulfate means increase from control to far-field areas.

The MANOVA for selected upper aquifer water chemistry constituents indicated significant variability for all constituents (P>F - <.05) in the area main effect except for fluoride. Significant variability for the year main effect was exhibited for chloride, fluoride, alkalinity and pH. The 1984 means were not significantly different from previous year's means. The general water quality pattern has remained unchanged over time and this pattern cannot be related to operations involving the dewatering/reinjection system.

B. MIS Modular Development Area

The lease suspension monitoring program is designed to detect and evaluate any effects that the MIS retorts or surface operations have on deep aquifer, surface waters and alluvial aquifers.

Spring and seep monitoring stations functioned as control sites. Mean conductivity and flow increased from 1983 to 1984, while the 1984 pH mean was consistent with the 1983 mean.

Stream station site field data were comparable to 1983 data, although flows at the beginning of 1984 were higher than previous years due to heavy precipitation in 1982 and 1983.

The 1984 water chemistry means from Box Elder Gulch were generally consistent with 1983 means, while Corral Gulch showed higher means in 1984 for most parameters. Consequently, all water chemistry means at the confluence of Box Elder and Corral Gulches (YMET3) were slightly higher in 1984 than in 1983, and most were higher at the lower Corral Gulch site (YSEOFL) in 1984. As seen in previous years, concentrations of major constituents increased between YMET3 and YSEOFL.

MANOVA techniques indicated that all stations were significantly different for sulfate among years. Magnesium, calcium, pH and TDS means were also highly variable among years at most stations.

Using USGS gage station data, the tract area, for the most part, was a net producer of water. This situation was reversed, however, in April, May and June due to heavy run-off upgradient from the tract. Flows at the USGS sites were low from October 1983 through March 1984. The flow increased to their peak measurements in May and returned to flows typical of previous years in September.

Daily field water quality means in 1984 were slightly higher than the 1983 means. Analysis of variance indicated that the mean daily flows, conductivity and temperature were significantly different among report years for each USGS station.

Most water chemistry constituents at the USGS sites were comparable to the 1983 analysis, although conductivity means were slightly higher at all sites in 1984, possibly due to leaching of soils exposed after the 1983 mud slide in upper Corral Gulch. The Duncan's analysis showed no significant differences between years for pH, alkalinity, sodium, potassium and boron. The most variable constituent among stations was sodium.

Mean water level measurements for alluvial wells during 1984 were consistent with the 1983 means in the control and far-field areas. The water levels rose appreciably in the near-field wells in July after the dewatering system was shut off in June. The 1984 field parameters of alluvial aquifers for all areas were comparable to the 1983 data except for mean conductivities in the control and near-field wells which were higher than seen in 1983. Alluvial pH for 1984 showed no spatial variation across the three monitoring areas.

Water chemistry data for alluvial wells was consistent with the 1983 analysis.

The alluvial aquifer MANOVA for water chemistry constituents indicated that the majority of major constitutents were significantly variable for area and year main effects. This analysis is essentially the same as the 1983 analysis, indicating the spatial pattern of alluvial water quality variability has not changed significantly over time.

Upper aquifer water level means were lowest in the control area, due to dewatering the first half of 1984, and highest in the far-field area. The near-field area exhibited the lowest means for pH and conductivity.

Upper aquifer water chemistry analysis indicated that pH, alkalinity and bicarbonate means increase from control to far-field areas.

The MANOVA results for selected water chemistry constituents of the upper aquifer indicated that significant temporal variability occurred for all constituents except TDS and conductivity. All constituents were significantly variable by area except for calcium, bicarbonate, sodium and fluoride. The 1984 means are similar to the 1978-1983 means for most major constituents, reflecting a fairly stable groundwater condition with no development-related impacts.

C. MIS Retort Abandonment Program

After termination of pumping in May 1984, water levels rose in the mine and retort systems. Water elevations rose nearly 460 feet in the first two months after flooding was initiated and about 70 feet between July 15 and the end of 1984. Discrepencies in water elevation data in and near the retorts, were explained by temperature and salinity differences between the retort and the mine system. Groundwater gradients near the retorts are essentially flat.

Pumping of the retort system indicated a definite connection between the retort and the mine systems. Response of near-retort RAM wells (-2, -5 and -6) were intermediate between that of the retort and the mine. The transmissivity of the upper aquifer was estimated to be 545 ft^2/day, less than

estimates from baseline studies but comparable to recent USGS modeling studies. A negative gradient toward the retort could be maintained with a pumping rate of 16 gpm within the retort system.

The RAM-7 well, with four completion zones within Retort 1 was completed in September 1984. Initial specific conductance ranged from nearly 12,000 micromhos per cm in RAM-7A near the top of the retort to 5000 to 6000 in the lower portions of the retort. The pH is over 12 in RAM-7A, decreasing to near 9 at the bottom of the retort (RAM-7G). Concentration of major ions in Retort 1 were fairly steady or declined slightly over the 1984 sampling period. Potassium, sodium and sulfates are the major inorganic ions. The total dissolved solids (TDS) concentrations within the retort is low compared to what one may expect based on literature/data on retorted shale leachates.

The results of this general evaluation for the four RAM-7 wells showed that nearly all major inorganic ions are at concentrations greater than the upper aquifer ambient P95 (95 percent confidence level) concentrations. Magnesium (Mg) and bicarbonate (HCO_3) are exceptions as they are found in concentrations less than the ambient mean in the retort (RAM-7 wells). Dissolved organic carbon (DOC) concentrations in the retort are between the ambient mean and P95 concentrations. This indicates that interaction between outlying RAM wells and the retort would be accompanied by high levels of most if not all of the major inorganic ions.

Trace constituents sampled (boron, lithium and molybdenuum) tended to show the lowest concentrations near the top of the retort. In a single sampling of 14 trace metals in the four RAM-7 wells only five were observed (in some samples) in measurable concentrations.

The mean dissolved organic carbon (DOC) ranged from 9 to 15 mg/l in the upper three RAM-7 wells, increasing to a mean of 30 mg/l in RAM-7G. This trend is expected since the flame front did not completely sweep the lower section of the retort. Of the 87 organic priority pollutants only one compound benzene, was measurable in all three of the upper well completions in

the retort, ranging from 11 to 28 parts per billion. RAM-7G exhibited more priority pollutant compounds, with benzene concentrations up to 51 ppb. These trace organic analyses are generally comparable to the types of compounds and concentrations observed in earlier samples collected from the retort system. Thus, as reported in the September 1983 abandonment plan proposal, there do not appear to be any compounds present at levels to individually produce significant toxic effects.

Some increases in specific conductance and potassium concentrations in near-retort wells may indicate an interconnection with the retort. However, the concentrations observed remain small relative to those observed in Retort 1 (RAM-7). Thus, the near retort water quality effects are not significant. In addition, a general increase in salinity of the upper aquifer near the mine was observed with the reflooding of this area. This is associated with leaching of soluble minerals exposed by mining and well drilling operations.

Organic priority pollutants were sampled in November 1984 in selected near-retort wells (RAM-2A,-2B,-5B) and in RAM-4B (used as a control). Only two compounds were quantifiable: benezene at 18 to 24 parts per billion near the retort and not detectable in RAM-4B; and di-N-butylphthalate in RAM-2A and 4B, probably indicating some contact of the sample with plastics at some point in the sampling/analysis procedures.

The general conclusion is that the initial retort abandonment program is progressing in a controlled fashion and there is no indication of environmental hazard to date.

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SECTION 6

SPECIAL STUDIES
ECOLOGICAL INTERRELATIONSHIPS

6.0 INTRODUCTION

In addition to the monitoring programs which have been reported in the previous sections of this report, RBOSC is conducting special studies in the following areas:

- Experimental Revegetation
- Mule Deer Habitat Modification
- Shrub Growth Enhancement
- Altering Natural Succession after Fire for Enhanced Deer-Livestock Forage
- Comparison of Inhalable and Total Suspended Particulates
- Run-of-Mine Lysimeters
- Effects of Surface Discharge on the Alluvial Aquifer

The activities during the 1984 reporting year in these areas are included in the Special Studies - Ecological Interrelationships section. The efforts included in this section are designed to examine means of mitigating development-related impacts by examining the relationships between the components of the ecosystems involved. The end result of these studies will be an increased understanding of the feasibility of modifying one ecosystem component (such as vegetative community physical structure and phytosociology) to produce a desired effect on another ecosystem component (such as wildlife).

6.1 REVEGETATION

A. Experimental Revegetation on Surface Disturbed Sites

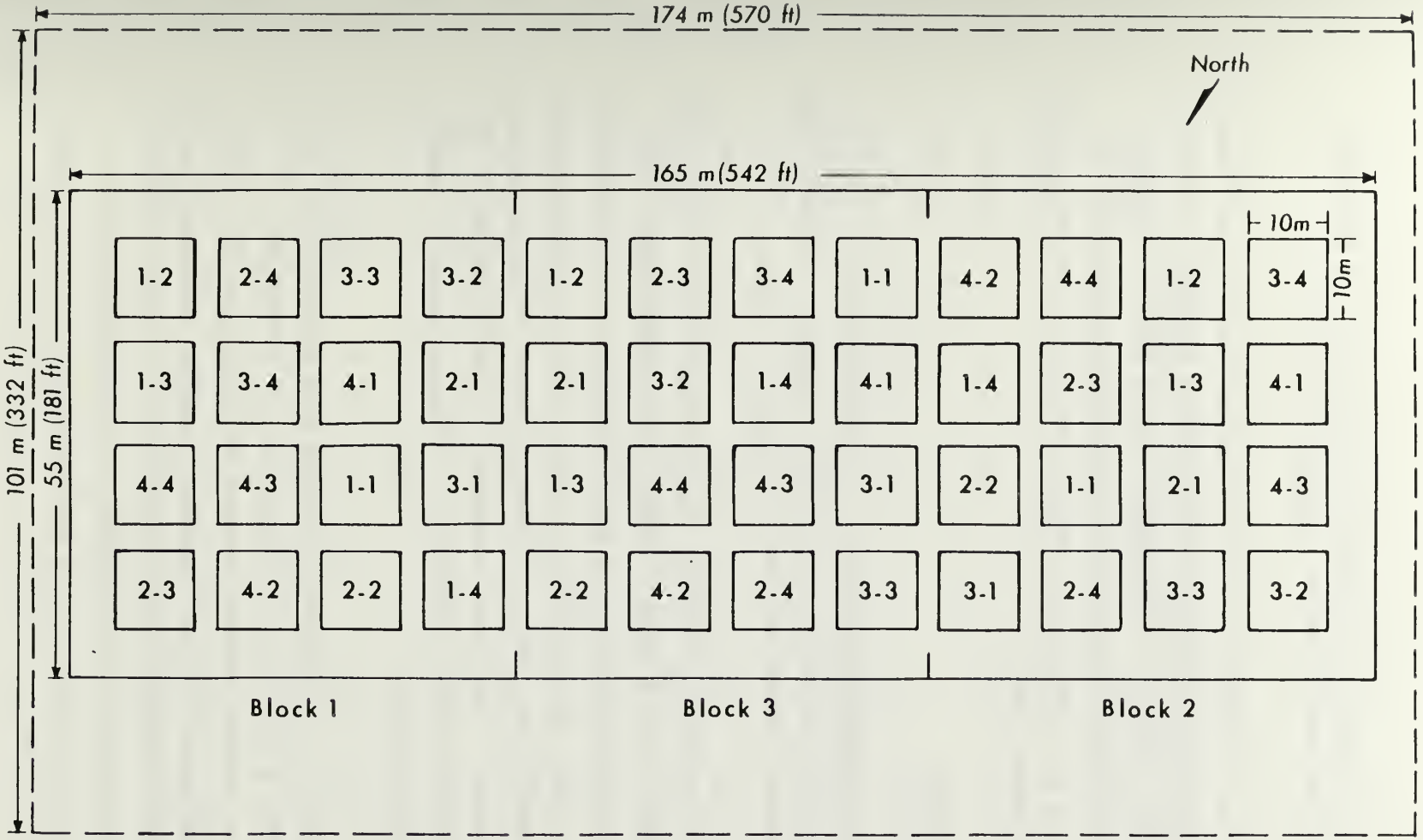
1. Objectives

The development of oil shale facilities on Tract C-a will result in disturbed lands which will be revegetated once disturbance ceases. Experiments were initiated during 1975 to demonstrate reclamation feasibility and species adaptability with varying mulch types, fertilizer applications and plot aspects.

2. Methods

Experimental plots were constructed at two locations in the southeast corner of Tract C-a; Plot R-1 was located on a northwestern exposure and Plot R-2 was located on a southeastern exposure. Surface disturbance at each site included stripping topsoil and subsoil, ripping the underlying rock substrate, and then replacing the subsoil and topsoil. Subsequent to these activities, the sites were seeded, mulched and/or fertilized using a total of 16 treatment combinations, with three replicates of each treatment applied at each site in a randomized block design. The configuration for Plot R-1 is illustrated in Figure 6-1. Additional information on methods is presented in Section 2.5.3.2 of Progress Report 4 (RBOSP 1975) and in Revegetation Annual Reports (RBOSC 1977, 1978, 1979).

Cover estimates within each treatment combination on Plots R-1 and R-2 were made within four m^2 quadrats (numbered 1-4) during 1976, 1977, 1978, 1980 and 1981. Biomass was determined within each of these same quadrats, in both 1978 and 1981, by clipping and drying the aboveground standing crop after cover estimates were made. Shrub species, however, were not clipped in 1981. In order to assess cover on quadrats undisturbed by previous clipping, four undisturbed quadrats were randomly selected in 1982 and sampled during 1982 through 1984 in each of the 16 treatment combinations, within each block on Plots R-1 and R-2. These new quadrats were numbered



Seeding Rate 18 kg/ha (16 lbs/acre)

Mulch Treatments:

(First Numeral in Treatment Designation)

1=No Mulch
2=Hydromulch
3=Straw Mulch Followed by Crimping
4=Straw Mulch With Netting

Fertilizer Treatments:

(180 kg/ha, 10-5-5)

(Second Numeral in Treatment Designation)

1=No Fertilizer
2=Fertilizer at Time of Sowing
3=Fertilizer at Beginning of First Full Growing Season
4=Fertilizer at Sowing & Beginning of First Full Growing Season

Figure 6-1. Treatment Configuration for Experimental Revegetation Plot R1, Tract C-a.

5-8, and will serve as the sample locations where cover will be estimated and aboveground biomass determined during subsequent years.

In order to facilitate an assessment of grazing pressure on the experimental revegetation plots, fencing was removed from two-thirds of each site during May 1984. For R-1, Block 1 remains fenced and for R-2, Block 3 remains fenced. During successive years, portions of the unfenced areas will be excluded from grazing so as to assess the impacts of grazing the revegetated areas for from one to several years.

3. Results and Discussion

a. Experimental Revegetation Plot R-1 - Cover estimates for species occurring on Plot R-1 were made August 5-6, 1984. These data are summarized in Table 6-1 and presented in their entirety in Appendix 6-1.1.

Cover for all species over the 16 treatment combinations ranged from 51.0 to 70.0 percent, with a mean of 63.2 percent (Table 6-1). The highest cover value was encountered on plots that had no mulch and which were fertilized at sowing. The lowest cover was exhibited on those plots with straw mulch held by crimping and fertilizer applied at sowing as well as the beginning of the first growing season. Mean cover recorded for 1984 decreased by 26 percent over that recorded for 1983 (Table 6-2). This decrease is largely related to planted grass species.

Planted grasses averaged 27.1 percent cover during 1984 and accounted for 42.9 percent of the total plant cover averaged over all treatment combinations. Cover of invader grasses averaged only 0.04 percent, which represented a marked decrease from that recorded in 1983. When compared to the 1976-1983 data, this represented the lowest cover of invader grasses recorded. Although grasses may have responded to increased moisture in 1983, the increase in cover noted for 1983 was not maintained during 1984. Nevertheless, cover of planted grass species was higher than all years except 1983.

TABLE 6-1. MEAN COVER (%) OF PLANTED AND INVADED GRASSES, FORBS, AND SHRUBS FOR EXPERIMENTAL REVEGETATION PLOT R-1 SAMPLED DURING THE CURRENT REPORT YEAR, 1984.

TREATMENT COMBINATION	GRASSES		FORBS		SHRUBS		TOTAL
	PLANTED	INVADED	PLANTED	INVADED	PLANTED	INVADED	COVER
NO MULCH NO FERTILIZER	26.1	.	33.8	1.3	4.4	0.3	65.9
NO MULCH FERTILIZER-SOWING	24.7	.	37.8	0.4	6.3	0.9	70.0
NO MULCH FERTILIZER-1ST GROWING	35.8	.	29.1	0.2	6.0	0.5	71.5
NO MULCH FERTILIZER-SOWING/1ST GROWING	21.1	.	35.2	0.9	7.9	0.8	65.9
HYDROMULCH NO FERTILIZER	24.5	.	31.8	1.1	5.3	0.1	62.8
HYDROMULCH FERTILIZER-SOWING	19.7	.	36.2	3.9	8.1	0.8	68.6
HYDROMULCH FERTILIZER-1ST GROWING	21.8	.	34.1	0.9	12.4	0.3	69.5
HYDROMULCH FERTILIZER-SOWING/1ST GROWING	21.3	0.3	39.1	1.1	6.8	0.4	68.9
STRAW-CRIMPING NO FERTILIZER	22.7	.	22.1	2.3	10.3	0.8	58.2
STRAW-CRIMPING FERTILIZER-SOWING	27.1	.	21.3	1.8	9.3	0.3	59.8
STRAW-CRIMPING FERTILIZER-1ST GROWING	17.1	0.2	27.8	3.4	3.7	0.7	52.8
STRAW-CRIMPING FERTILIZER-SOWING/1ST GROWING	28.3	.	14.6	1.6	6.3	0.3	51.0
STRAW-NETTING NO FERTILIZER	39.2	.	20.5	1.1	3.4	1.5	65.7
STRAW-NETTING FERTILIZER-SOWING	28.8	.	18.1	0.9	6.3	0.6	54.7
STRAW-NETTING FERTILIZER-1ST GROWING	42.5	0.2	17.8	1.4	2.4	0.4	64.7
STRAW-NETTING FERTILIZER-SOWING/1ST GROWING	33.6	.	16.5	0.9	8.0	2.6	61.6
MEAN COVER	27.1	0.0	27.2	1.5	6.7	0.7	63.2

Table 6-2. Comparison of Mean Cover (%) Among Years for All Treatment Combinations on Experimental Revegetation Plot R-1, Tract C-a.

Growth Form	Year							
	1976	1977	1978	1980	1981	1982[1/]	1983[1/]	1984[1/]
Grasses Planted	5.9	12.2	10.9	18.4	20.7	21.3	41.9	27.1
Grasses Invaded	2.5	0.1	0.5	3.4	3.5	4.1	7.0	0.0
Forbs Planted	3.6	4.1	1.7	9.8	10.6	16.1	23.8	27.2
Forbs Invaded	10.2	23.4	20.9	6.0	4.5	3.4	4.5	1.5
Shrubs Planted	2.1	3.3	3.7	3.0	2.7	4.4	7.3	6.7
Shrubs Invaded	0.0	0.0	0.1	0.1	0.8	0.4	0.8	0.7
TOTAL	24.5	43.1	37.8	40.7	42.8	49.8	85.2	63.2

1/ Data are based on cover estimates from sample quadrats established in 1982.

The proportional cover between treatment combinations on Plot R-1 remained essentially the same as for 1983. Highest cover of planted grasses was recorded on areas receiving straw mulch held by netting and no fertilizer. Lowest cover was noted on areas where straw mulch was crimped and fertilizer applied at the beginning of the first growing season (Table 6-1). Although identification of species was hampered somewhat by the impacts of grazing, the dominant planted grasses continued to be the wheatgrass (Agropyron) species. Green needlegrass (Stipa viridula) and Indian ricegrass (Oryzopsis hymenoides), when present, contributed only about one percent cover. It appears that wheatgrass species have continued to flourish at the expense of other planted species.

A statistical comparison of 1984 cover data for planted grasses between treatment combinations revealed no significant main effect, first order or second order interactions (Table 6-3). The sample size for invader grasses was not large enough to produce ANOVA results. Significant differences among blocks, which were expected due to variations in grazing pressure between fenced and unfenced portions of Plot R-1, were not evident for grass species. Such differences may become evident once the plots are grazed for several years or when aboveground biomass is measured.

Cover of planted forbs (27.2 percent) during 1984 accounted for 43 percent of the total mean cover for all treatment combinations (Table 6-1). Cover increased from the 23.8 percent recorded in 1983 and the proportion of planted forbs to all vegetation cover increased markedly, probably because of the pronounced decrease in grasses (Table 6-2). Invader forb species decreased in cover, from 4.5 in 1983 to 1.5 percent in 1984.

The distribution of forb cover among the various treatment combinations changed somewhat in 1984 relative to that reported in 1982 and 1983. Highest cover of planted species, primarily cicer milkvetch (Astragalus cicer var Lutana), Lewis flax (Linum lewisii), and yellow sweetclover (Melilotus officinalis var Madrid), was recorded on plots which had been hydromulched and which received fertilizer as sowing and at the beginning of the first growing season (Table 6-1). The highest cover of invader forbs was found in

Table 6-3. Results of Three-way ANOVA's Comparing Arcsine Transformed Grass, Forb and Shrub Cover Estimates for Planted and Invaded Species Among Treatment Combinations During 1984 on Experimental Revegetation Plot R-1, Tract C-a[1/]

Growth Form	Source of Variation: Block F	Block PR>F[2/]	Mulch F	Mulch PR>F[2/]	Fertilizer F	Fertilizer PR>F[2/]	Block x Mulch F	Block x Mulch PR>F[2/]	Block x Fertilizer F	Block x Fertilizer PR>F[2/]	Mulch x Fertilizer F	Mulch x Fertilizer PR>F[2/]	Block x Mulch x Fertilizer F	Block x Mulch x Fertilizer PR>F[2/]
Grasses Planted	0.44	0.6529	1.93	0.1712	0.60	0.6285	0.50	0.7964	0.19	0.9747	0.73	0.6741	0.23	0.9978
Grasses Invaded[3/]														
Forbs Planted	2.34	0.1020	2.72*	0.0482	0.06	0.9756	0.29	0.9417	0.30	0.9374	0.16	0.9965	0.26	0.9989
Forbes Invaded	5.68**	0.0050	1.40	0.2495	0.26	0.8562	0.69	0.6582	2.52*	0.0277	1.36	0.2201	1.07	0.3978
Shrubs Planted	0.77	0.4647	0.27	0.8506	0.24	0.8662	0.87	0.5182	1.13	0.3499	1.37	0.2111	1.06	0.4078
Shrubs Invaded[3/]														

* Significant at $\alpha = 0.05$

** Significant at $\alpha = 0.025$

1/ Duncan's Multiple Range Test results for significant main effects are presented in Appendix 6-1.2.

2/ Represents the significance probability (α) associated with F.

3/ Missing values occur when there is insufficient data to produce ANOVA results.

areas with hydromulch and where fertilizer had been applied at sowing. Cover of yellow sweetclover increased threefold over that recorded in 1983. No single invader forb species approached the cover of planted species; however, Scarlet gilia (Ipomopsis aggregata), Douglas chaenactis (Chaenactis douglasii), and Machaeranthera species continued to be frequent minor contributors to cover (Appendix 6-1.1). Invader forb species for 1984 exhibited cover lower than that recorded since studies began in 1976 (Table 6.2).

Statistical comparisons for 1984 data showed significant differences based on the mulch main effect for planted forbs and the block main effect for invader forbs (Table 6-3). Duncan's Multiple Range Test results indicated that cover of planted forbs was significantly higher on the no mulch treatments than for any of the mulch treatments tested (Appendix 6-1.2). Cover of invader forbs was significantly higher on Block 1 than the other two blocks. Because Block 1 remains fenced while the remainder of the study site is now open to grazing, these results seem to indicate that grazing has thus far not facilitated invasion from surrounding plant communities. In fact, the opposite effect seems to be the case for invader forb species. It remains to be seen what effects grazing will have on the long-term composition of species on this site.

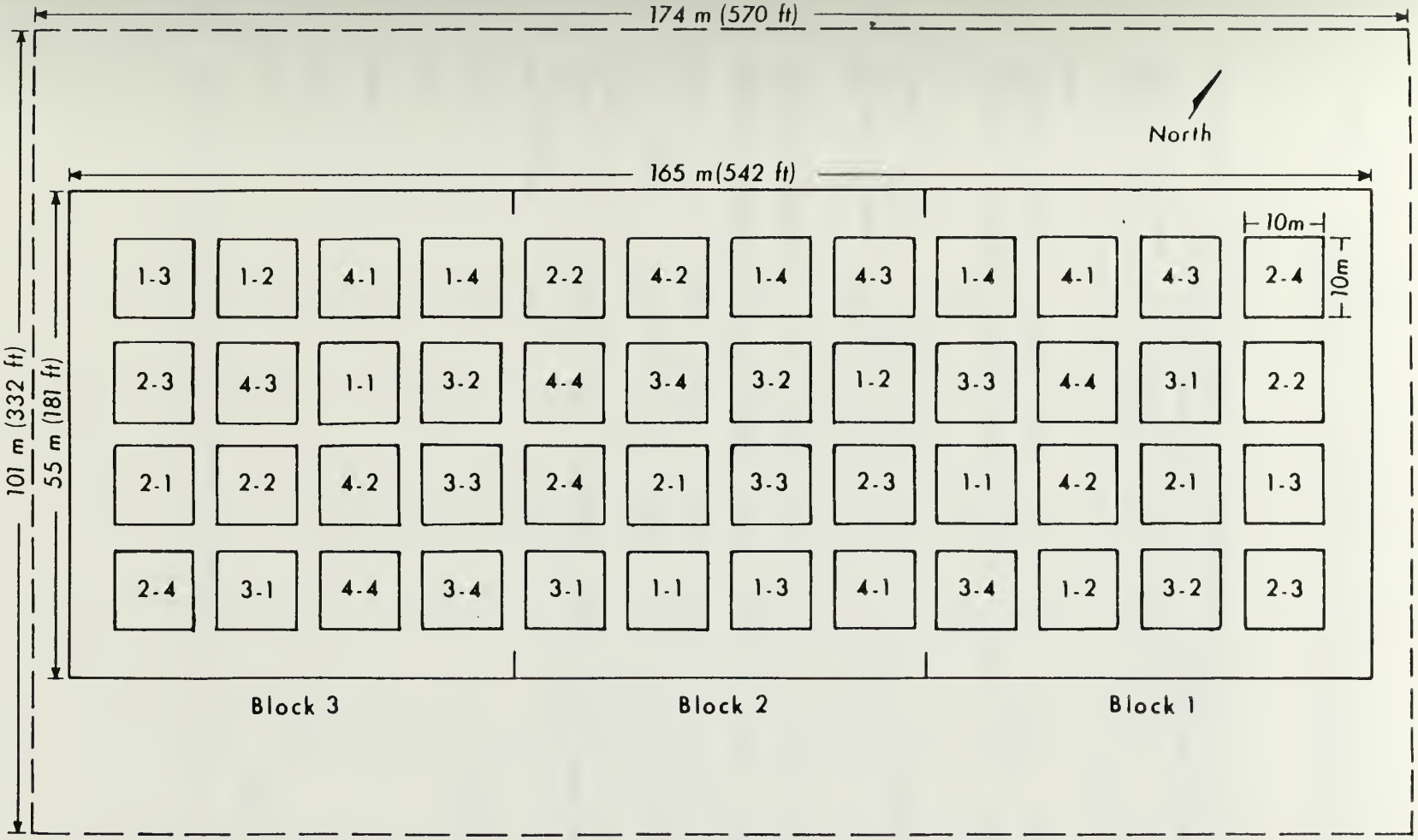
Cover of planted shrub species decreased slightly from 7.3 percent in 1983 to 6.7 percent in 1984. However, as a proportion of total mean cover on Plot R-1, cover of planted shrub species during 1984 (10.6 percent) was slightly higher than that evidenced in 1982 and 1983 (8.8 and 8.6, respectively). Cover of invader shrub species changed little in 1984 relative to 1983 (Table 6-2). Broom snakeweed (Gutierrezia sarothrae) continued to be the only invader species encountered, whereas big sagebrush (Artemisia tridentata), winterfat (Ceratoides lanata), and rubber rabbitbrush (Chrysothamnus nauseosus) were relatively common planted species. The general distribution of shrub cover among treatment combinations was the same as recorded in 1982 and 1983.

No significant differences among treatments were noted for shrub cover during 1984 (Table 6-3). However, cover during 1983 and 1984 continued to be markedly higher than for the other six years of record. Data indicate that growth of shrubs, as well as forbs, has apparently continued to respond to increased precipitation, whereas there has been a decrease in cover of grasses.

b. Experimental Revegetation Plot R-2 - Cover estimates for species occurring on Plot R-2 were made August 30 and September 4-5, 1984. The Plot R-2 configuration is illustrated on Figure 6-2. Data collected during 1984 are summarized on Table 6-4 and are presented in their entirety in Appendix 6-1.3.

Cover for all species over the 16 treatment combinations ranged from 43.2 to 75.7 percent, with a mean of 56.4 percent (Table 6-4). The trend in cover among treatment combinations changed slightly from that recorded in 1983. Highest cover was encountered on plots which received straw mulch held in place by netting and which were not fertilized. The lowest cover was noted where no mulch treatment was used and where fertilization occurred at the beginning of the first growing season. Mean cover over all treatment plots during 1984 (56.4 percent) decreased slightly from the 62.0 percent average cover noted during 1983 (Table 6-5). The decreased cover noted for R-2 during 1984 relative to 1983 was considerably less than the corresponding decrease noted for R-1 (Table 6-2).

Cover of planted grasses averaged 19.4 percent during 1984 and accounted for 34 percent of total cover averaged over all treatment combinations. Invader grasses averaged 0.4 percent cover. Although increases in cover of both planted and invader species were substantial in 1983 as compared to 1982, during 1984 total mean cover attributable to planted species remained essentially the same whereas cover of invader grasses decreased markedly. Highest cover of planted species was noted on areas which received straw mulch held in place by netting but which received no fertilizer. The same treatment combination had the greatest cover in 1982 and 1983 as well.



Seeding Rate 18 kg/ha (16 lbs/acre)

Mulch Treatments:
(First Numeral in Treatment Designation)

1=No Mulch
2=Hydromulch
3=Straw Mulch Followed by Crimping
4=Straw Mulch With Netting

Fertilizer Treatments:
(180 kg/ha, 10-5-5)
(Second Numeral in Treatment Designation)

1=No Fertilizer
2=Fertilizer at Time of Sowing
3=Fertilizer at Beginning of First Full Growing Season
4=Fertilizer at Sowing & Beginning of First Full Growing Season

Figure 6-2. Treatment Configuration for Experimental Revegetation Plot R2, Tract C-a.

TABLE 6-4. MEAN COVER (%) OF PLANTED AND INVADED GRASSES, FORBS, AND SHRUBS FOR EXPERIMENTAL REVEGETATION PLOT R-2 SAMPLED DURING THE CURRENT REPORT YEAR, 1984.

TREATMENT COMBINATION	GRASSES		FORBS		SHRUBS		TOTAL COVER
	PLANTED	INVADED	PLANTED	INVADED	PLANTED	INVADED	
NO MULCH NO FERTILIZER	14.4	0.3	18.2	2.9	14.3	0.6	50.6
NO MULCH FERTILIZER-SOWING	18.2	0.2	18.8	2.4	14.1	.	53.6
NO MULCH FERTILIZER-1ST GROWING	15.5	0.2	10.4	2.0	15.2	.	43.2
NO MULCH FERTILIZER-SOWING/1ST GROWING	18.3	2.7	9.1	3.2	26.3	.	59.5
HYDROMULCH NO FERTILIZER	14.8	0.3	7.5	0.9	26.3	3.2	53.0
HYDROMULCH FERTILIZER-SOWING	17.7	0.3	13.2	2.8	17.8	0.7	52.4
HYDROMULCH FERTILIZER-1ST GROWING	16.5	0.3	12.1	2.2	20.3	2.6	53.8
HYDROMULCH FERTILIZER-SOWING/1ST GROWING	19.4	0.3	13.3	3.6	14.8	0.9	52.2
STRAW-CRIMPING NO FERTILIZER	17.6	.	21.6	0.9	15.8	3.0	58.8
STRAW-CRIMPING FERTILIZER-SOWING	20.8	0.8	22.0	1.3	20.7	2.5	68.2
STRAW-CRIMPING FERTILIZER-1ST GROWING	18.2	0.1	13.8	2.7	19.9	1.8	56.4
STRAW-CRIMPING FERTILIZER-SOWING/1ST GROWING	17.5	.	16.8	2.1	15.9	0.5	52.7
STRAW-NETTING NO FERTILIZER	31.3	1.3	20.0	0.8	21.5	0.9	75.7
STRAW-NETTING FERTILIZER-SOWING	23.4	.	12.6	1.4	14.9	0.5	52.8
STRAW-NETTING FERTILIZER-1ST GROWING	23.8	0.3	6.9	3.3	19.0	1.1	54.2
STRAW-NETTING FERTILIZER-SOWING/1ST GROWING	23.3	0.3	16.3	2.3	22.0	1.0	65.2
MEAN COVER	19.4	0.4	14.5	2.2	18.7	1.2	56.4

Table 6-5. Comparison of Mean Cover (%) Among Years for All Treatment Combinations on Experimental Revegetation Plot R-2, Tract C-a.

Growth Form	Year							
	1976	1977	1978	1980	1981	1982[1/]	1983[1/]	1984[1/]
Grasses Planted	4.6	9.0	8.1	15.1	11.5	14.0	21.8	19.4
Grasses Invaded	2.6	0.1	0.4	0.8	1.3	1.6	2.7	0.4
Forbs Planted	2.8	3.3	2.5	8.3	7.3	9.8	15.1	14.5
Forbs Invaded	5.6	21.1	12.9	6.8	3.6	1.9	2.2	2.2
Shrubs Planted	1.4	2.6	4.7	6.2	5.6	10.5	18.9	18.7
Shrubs Invaded	0.0	0.0	0.0	0.1	0.4	0.8	1.2	1.2
TOTAL	17.0	36.1	28.5	37.3	29.7	38.6	62.0	56.4

1/ Data are based on cover estimates from sample quadrats established in 1982.

Lowest cover of planted species was encountered on areas which received no fertilizer or mulch. Wheatgrass species and Indian ricegrass were the most frequently encountered planted grasses. The highest cover of invader species, primarily crested wheatgrass (Agropyron cristatum) and squirreltail, occurred among treatments with no mulch but with fertilizer applications both at sowing and during the first growing season (Table 6-4). As noted in previous reports, the differences among treatments noted this long after application of the mulch and/or fertilizer are likely not directly related to the amendments, but rather are artifacts of the study design and/or related to competition among species which began within several years after planting.

Statistical comparison of 1984 cover data for planted or invader grasses between treatment combinations revealed no significant main or interaction effects (Table 6-6). Therefore, neither the mulch nor fertilizer treatments seemed to be influencing cover nine years after planting. No significant effects on cover were evident during the first year that Blocks 1 and 2 were opened to grazing. However, identification of grass species was hampered by grazing.

Cover of planted forb species on Plot R-2 averaged 14.5 percent during 1984, which accounted for 25.7 percent of the average cover over all treatments (Table 6-4). This represents a slight decrease in cover relative to 1983 (Table 6-5), but a slight increase in the proportion which planted forbs contributed relative to all species. Invader forb species cover (2.2 percent) remained the same as for 1983. The highest cover of planted species (22.0 percent) was encountered on areas which were fertilized at sowing and which received straw mulch held by crimping. The highest cover of invader species was recorded on areas which received hydromulch and which were fertilized at sowing as well as the beginning of the first growing season. Cicer milkvetch and Lewis flax continue to be the most prevalent planted forb species encountered. Yellow sweetclover and Utah sweetvetch (Hedysarum utahensis) contributed low cover relative to the flax and milkvetch (Appendix 6-1.3). There was little change, if any, in the composition of invader

Table 6-6. Results of Three-way ANOVA's Comparing Arcsine Transformed Grass, Forb and Shrub Cover Estimates for Planted and Invaded Species Among Treatment Combinations During 1984 on Experimental Revegetation Plot R-2, Tract C-a[1/]

Growth Form	Source of Variation: Block F	Block PR>F[2/]	Mulch F	Mulch PR>F[2/]	Fertilizer F	Fertilizer PR>F[2/]	Block x Mulch F	Block x Mulch PR>F[2/]	Block x Fertilizer F	Block x Fertilizer PR>F[2/]	Mulch x Fertilizer F	Mulch x Fertilizer PR>F[2/]	Block x Mulch x Fertilizer F	Block x Mulch x Fertilizer PR>F[2/]
Grasses Planted	1.48	0.2347	1.42	0.2436	0.24	0.8671	0.38	0.8920	0.21	0.9741	0.07	0.9998	0.19	1.0000
Grasses Invaded[3/]	0.06	0.9416	0.13	0.9348	0.57	0.6884	0.86	0.5380	0.00	0.9693	1.07	0.5159		
Forbs Planted	0.34	0.7149	1.88	0.1403	0.76	0.5246	0.50	0.8048	0.12	0.9934	0.30	0.9705	0.53	0.9338
Forbes Invaded	0.24	0.7891	1.03	0.3824	1.28	0.2867	0.39	0.8852	1.03	0.4128	1.36	0.2184	0.72	0.7849
Shrubs Planted	1.44	0.2433	0.17	0.9106	0.10	0.9531	0.46	0.8333	0.20	0.9759	0.64	0.7608	0.49	0.9544
Shrubs Invaded[3/]														

* Significant at $\alpha = 0.05$

** Significant at $\alpha = 0.025$

1/ Duncan's Multiple Range Test results have not been included in the appendix because significant main effects were not evident.

2/ Represents the significance probability (α) associated with F.

3/ Missing values occur when there is insufficient data to produce ANOVA results.

species, Douglas chaenactis, cryptantha (Cryptantha sericia), Machaeranthera and lobeleaf groundsel (Senecio multilobatus) being the most common species.

Results of the three-way ANOVA comparing 1984 forb cover among treatment combinations show no significant main or interaction effects (Table 6-6). However, comparison of forb cover among years (Table 6-5) indicates that, aside from 1983, cover of planted species during 1984 was higher than for all other sample periods. Cover of invader species, on the other hand, was similar to 1982 and 1983. High cover of planted species during 1983 and 1984 may be related in increased moisture during the growing season.

Shrub cover for planted species averaged 18.7 percent over all treatment combinations during the 1984 sample period, with the range being from 14.1 to 26.3 percent (Table 6-4). Cover of planted shrub species accounted for 33 percent of total mean cover for all species. Cover of invaders species averaged 1.2 percent during 1984, with a range of zero to 3.2 percent. Cover of shrub species was very similar to that for 1983.

Areas which received hydromulch and no fertilizer, and those with no mulch but fertilization both at the time of sowing and during the first growing season, shared the highest cover of planted shrubs. The lowest cover was encountered on areas which were treated with three different mulch and/or fertilizer treatments (Table 6-4). Rubber rabbitbrush was the greatest contributor to cover of planted shrub species, with winterfat, fourwing saltbrush (Atriplex canescens) and antelope bitterbrush (Purshia tridentata) being somewhat less common and contributing lower cover. Broom snakeweed was the only invader shrub species encountered on Plot R-2. A statistical comparison of cover of planted shrubs among the various treatment combinations for 1984 indicated no significant main or interaction effects (Table 6-6).

c. Precipitation - Average rainfall at Meteorological Monitoring Site 1 during 1984 ranged from 19.6 to 22.14 inches depending on the gauge used (see Table 2-18, Chapter 2). This represented a high for the last seven

years of monitoring. Wedge gauge readings during the May-October period were 13.9 inches at Site 1 as compared to 13.8 inches at Plot R-1 and 13.9 inches at Plot R-2 during the corresponding period. Plot R-3 received 15.8 inches of precipitation for May-October.

Relatively uniform precipitation during the growing season seems to be contributing to the high vegetative cover noted during 1983-1984 as compared to earlier years. Typically there has been a pronounced lack of precipitation on Tract C-a during mid-June through July. During June and July of 1984, 4.7 inches of precipitation were recorded, thus allowing for the maintenance of growth throughout the summer.

B. Experimental Revegetation on a Simulated Processed Shale Disposal Site

1. Objectives

During RBOSC's demonstration of surface retorting technology and subsequent commercial operations, processed shale will be produced as a by-product of surface retorting. This material will require surface disposal because not all of the processed shale can be returned to an open pit mine. RBOSC initiated revegetation experiments in 1976 to determine a feasible method of reestablishing a productive, self-sustaining livestock and/or wildlife habitat on processed shale disposal sites.

2. Methods

Revegetation Plot R-3 was established in the fall of 1976, and is located near the southeastern corner of Tract C-a. The plot is situated in an area with a southeast-facing aspect and a slope of approximately 20 percent.

The plot is designed to simulate an artificial soil profile for use in overburden/processed shale disposal piles. This profile, from bottom to top, consists of 0.45 m of compacted Tosco II processed shale, 0.9 m of segregated sized overburden-like material, 0.3 m of subsoil, and 0.15 m of topsoil. The overburden-like material (0.9 m) is expected to inhibit the

capillary migration of soluble, potentially toxic components from the processed shale into the surface plant growth medium. The treatment configuration at Plot R-3 is designed to test the effectiveness of this reconstructed soil profile, as well as various seeding rates and mulch regimes (Figure 6-3). Portions of Plot R-3 underlain by processed shale are considered treatments while those without processed shale serve as controls.

During 1984 cover was assessed within three 1 m^2 quadrats within each of the 36 treatment plots. These sample quadrats were the same as those randomly selected and sampled during 1982 and 1983.

Soil moisture samples (percent volume) scheduled for collection in 1984 from three depths (approximatley 25 cm, 75 cm and 150 cm) within permanently established holes centered above each of 36 plots on R-3 were not obtained due to equipment malfunction. Soil moisture samples were to be obtained monthly from May-October using a Troxler neutron probe depth moisture gauge. Gauge reading were to be corrected for the non-water hydrogen component of the reading using correction factors determined at the time access tubes were established in 1982. Continued use of these correction factors is based on the assumption that hydrogen associated with such things as organics remains relatively constant. Sampling of soil moisture will be resumed during 1985.

Additional information on experimental revegetation Plot R-3 is available in MDP Monitoring Report 5 (RBOSC 1980) and in Revegetation Annual Reports (RBOSC 1977, 1978, 1979a).

3. Results and Discussion

a. Cover Data - Cover for grasses, forbs, and shrubs on Plot R-3 was estimated July 31-August 2, 1984. These data are summarized on Table 6-7 and presented in their entirety in Appendix 6-1.4.

Cover for all species averaged 70.4 percent on the control (no processed shale) portion of R-3, with the range being from 57.7 to 87.5 percent.

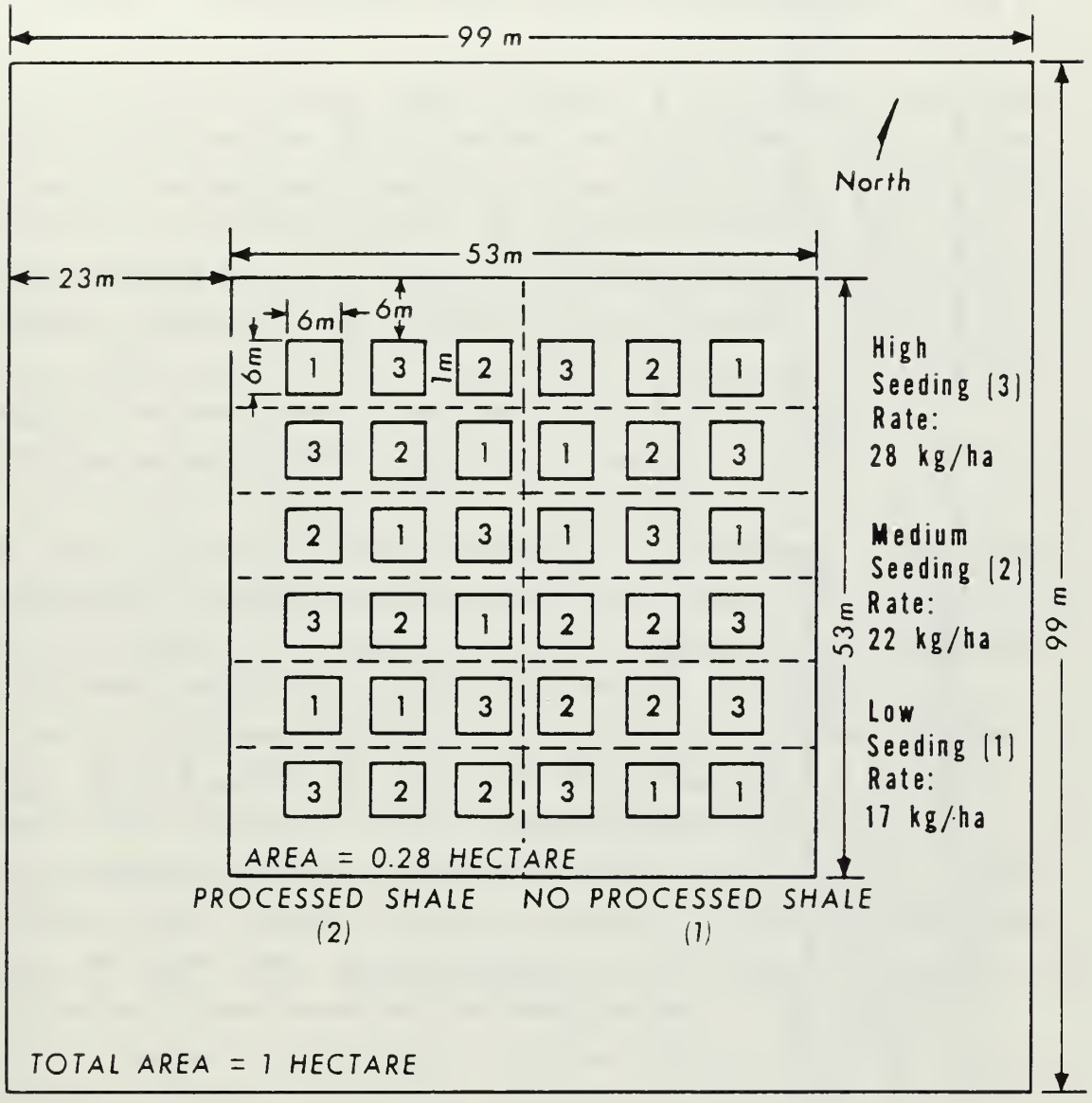


Figure 6-3. Configuration of Experimental Revegetation Plot over 'Tosco II' Processed Shale.

TABLE 6-7. COVERAGE (%) OF PLANTED AND INVADED GRASSES, FORBS, AND SHRUBS FOR EXPERIMENTAL REVEGETATION PLOT R-3 (SUBPLOTS 4, 5, AND 6) DURING THE CURRENT REPORTING YEAR, 1984

TREATMENTS COMBINATIONS	CONTROL (NO PROCESSED SHALE)							TREATMENT (PROCESSED SHALE)						
	GRASSES		FORBS		SHRUBS		TOTAL	GRASSES		FORBS		SHRUBS		TOTAL
	PLANTED	INVADED	PLANTED	INVADED	PLANTED	INVADED	COVER	PLANTED	INVADED	PLANTED	INVADED	PLANTED	INVADED	COVER
HAY MULCH LOW SEEDING	23.7	9.7	11.8	0.2	28.0	.	73.3	32.8	11.5	12.7	0.3	21.5	0.3	79.2
HYDROMULCH LOW SEEDING	25.3	8.2	11.0	0.3	8.2	4.7	57.7	22.5	1.0	3.3	1.2	28.3	1.7	59.0
NO MULCH LOW SEEDING	27.0	2.8	11.0	.	20.0	0.7	61.5	52.3	1.3	11.2	0.5	9.3	0.5	75.2
HAY MULCH MEDIUM SEEDING	25.5	17.5	16.0	0.5	7.5	0.8	67.8	30.8	8.2	18.7	0.5	22.5	0.8	81.5
HYDROMULCH MEDIUM SEEDING	31.7	3.8	13.7	2.5	16.5	2.8	71.0	25.5	2.2	21.2	0.8	37.2	.	86.8
NO MULCH MEDIUM SEEDING	31.3	1.5	9.0	2.2	8.5	4.7	57.2	33.0	1.3	13.2	0.8	18.3	2.0	68.7
HAY MULCH HIGH SEEDING	39.8	2.2	23.2	1.2	17.8	.	84.2	33.8	4.3	7.8	2.3	31.0	0.7	80.0
HYDROMULCH HIGH SEEDING	42.7	0.7	28.7	0.3	14.8	0.3	87.5	31.8	.	23.7	1.7	31.8	.	89.0
NO MULCH HIGH SEEDING	43.8	.	17.5	0.5	10.8	0.3	73.0	37.5	.	8.0	3.5	31.3	.	80.3
MEAN COVER	32.3	5.1	15.8	0.9	14.7	1.6	70.4	33.4	3.3	13.3	1.3	25.7	0.7	77.6

Average cover on the treatment (underlain by processed shale) portion of R-3 was 77.6 percent, with the range being from 58.0 to 89.0 percent (Table 6-7).

Highest and lowest total cover determinations for the treatment (processed shale) portion of the site were encountered on the hydromulch-high seeding and hydromulch-low seeding, respectively. The distribution of total cover on the control (no shale) portion of the site was the same as that noted for the shale treatment portion of the plot. Cover of all species averaged over all treatment combinations has increased from 43.5 percent in 1982 to 64.3 percent in 1983 and 74.1 in 1984 (Table 6-8). As discussed for Plots R-1 and R-2, this increase seems to be due in large part to increased precipitation during the 1983 -1984 growing seasons.

Planted grasses averaged 32.8 percent cover for all treatment combinations, or 44.3 percent of total mean cover (Table 6-8). Invader grass species averaged 4.3 percent cover, accounting for 5.7 percent of total mean cover. Cover of planted species increased in 1984 relative to 1983 and the proportion of total cover attributable to planted grasses also increased slightly. Invader species, on the onther hand, experienced a 2.5-fold decrease in cover relative to 1983. Invader species continued to be primarily cheatgrasses and/or crested wheatgrass (Appendix 6-1.4). Among the planted grasses, wheatgrass species continued to dominate, with Indian ricegrass and smooth brome (Bromus inermis) being encountered frequently but contributing much lower cover than the wheatgrasses. If wheatgrasses continue to flourish, it is unlikely that other planted or invader species will increase in cover.

A statistical comparison of 1984 cover data for all planted and invader grasses showed that there was only one significant difference based on the treatment combinations tested (Table 6-9). Invader grass species showed significant differences in cover based on mulch treatments. However, Duncan's Multiple Range Test results did not confirm such differences. When cover based on individual planted grass species was compared among treatments, no significant main effect differences were noted (Table 6-10). Several significant interaction effect differences were recorded for Indian

Table 6-8. Comparison of Mean Cover (%) Among Years for All Treatment Combinations on Experimental Revegetation Plot R-3, Tract C-a.

Growth Form	Year							
	1977	1978	1979	1980	1981	1982[1]/	1983[1]/	1984[1]/
Grasses Planted	5.6	14.0	28.8	24.7	22.7	17.4	26.0	32.8
Grasses Invaded	0.8	0.5	1.5	3.4	3.0	4.1	10.4	4.2
Forbs Planted	8.0	5.1	3.5	4.0	7.3	6.6	10.6	14.6
Forbs Invaded	1.2	0.6	0.9	0.4	0.3	0.8	0.4	1.1
Shrubs Planted	4.7	7.2	16.7	4.0	4.4	13.6	16.1	20.2
Shrubs Invaded	0.0	0.1	0.2	0.1	0.2	1.0	0.8	1.2
TOTAL	20.3	27.5	51.6	36.6	37.9	43.5	64.3	74.1

1/ Data are based on cover estimates from sample quadrats established in 1982.

Table 6-9. Results of Three-way ANOVA's Comparing Arcsine Transformed Cover Estimates for Planted and Invaded Grass, Forb, and Shrub Species During 1984 on Experimental Revegetation Plot R-3, Tract C-a.[1/]

Growth Form	Source of Variation													
	Substrate		Mulch		Seeding		Substrate x Mulch		Substrate x Seeding		Mulch x Seeding		Substrate x Mulch x Seeding	
	F	PR>F[2/]	F	PR>F[2/]	F	PR>F[2/]	F	PR>F[2/]	F	PR>F[2/]	F	PR>F[2/]	F	PR>F[2/]
Grasses Planted	0.39	0.5360	0.06	0.9425	1.79	0.1717	0.50	0.6083	0.42	0.6557	0.10	0.9823	0.36	0.8376
Grasses Invaded	0.62	0.4391	3.60*	0.0421	0.48	0.6260	0.38	0.6871	0.27	0.7641	0.07	0.9752	0.53	0.5946
Forbs Planted	0.24	0.6291	0.43	0.6568	0.50	0.6139	0.06	0.9412	1.12	0.3387	1.20	0.3276	0.24	0.9145
Forbes Invaded	0.52	0.4745	0.29	0.7530	1.97	0.1568	0.29	0.7530	3.75*	0.0347	1.23	0.3168	0.19	0.8993
Shrubs Planted	9.27**	0.0029	0.90	0.4106	0.45	0.6393	2.27	0.1083	1.32	0.2717	0.22	0.9277	1.16	0.3332
Shrubs Invaded[3/]	0.60	0.4729	0.08	0.9229	0.38	0.7002	0.02	0.9769	0.34	0.7240	0.30	0.8235		

* Significant at $\alpha = 0.05$

** Significant at $\alpha = 0.025$

1/ Duncan's Multiple Range Test results for significant main effects are presented in Appendix 6-1.5.

2/ Represents the significance probability (α) associated with F.

3/ Missing values occur when there is insufficient data to produce ANOVA results.

Table 6-10. Results of Three-way ANOVA's Comparing Arcsine Transformed Cover Estimates for Planted Species Encountered During 1984 on Experimental Revegetation Plot R-3, Tract C-a.[1/]

Growth Form	Source of Variation: Substrate F	Substrate PR>F[2/]	Mulch F	Mulch PR>F[2/]	Seeding F	Seeding PR>F[2/]	Substrate x Mulch F	Substrate x Mulch PR>F[2/]	Substrate x Seeding F	Substrate x Seeding PR>F[2/]	Mulch x Seeding F	Mulch x Seeding PR>F[2/]	Substrate x Mulch x Seeding F	Substrate x Mulch x Seeding PR>F[2/]
Grasses Planted														
Agropyron species	0.38	0.5467	1.96	0.1701	1.69	0.2134	2.52	0.1088	2.68	0.0961	0.71	0.5964	0.22	0.3355
Agropyron trichophorum	0.05	0.8297	0.10	0.9059	0.94	0.4090	1.00	0.3860	0.49	0.6198	0.22	0.9231	0.54	0.7099
Bromus ineris	0.18	0.6924	0.66	0.5584	0.24	0.7952	0.00	0.9844	0.38	0.7013	0.74	0.6019	0.03	0.8652
Orysopsis hymenoides	0.46	0.5238	0.68	0.5396	0.11	0.8989	1.24	0.3540	6.71*	0.0295	3.41	0.0938	5.89*	0.0385
Stipa viridula	0.05	0.8346	0.25	0.7910	0.67	0.5629	1.09	0.4182	0.05	0.8287	1.17	0.3396		
Forbs Planted														
Astragalus cicer	0.33	0.5712	0.58	0.5691	1.11	0.3526	1.02	0.9758	1.02	0.3802	0.64	0.6392	0.15	0.9608
Linum lewisii[3/]														
Melilotus officinalis[3/]														
Shrubs Planted														
Artemisia tridentata[3/]	1.23	0.4674	2.86	0.3855	0.85	0.6093	43.56	0.0957	7.57	0.2489	0.72	0.5522		
Atriplex canescens	3.56	0.0800	0.02	0.9795	2.44	0.1233	3.54	0.0570	5.83**	0.0144	1.72	0.2017	0.27	0.7637
Chrysothamnus nauseosus[3/]	5.21	0.0518	5.87*	0.0270	0.23	0.7966	1.24	0.3389	0.26	0.7769	1.37	0.3250		
Certatoides lanata	6.16*	0.0264	1.44	0.2709	1.48	0.2618	0.87	0.4404	4.70*	0.0274	0.45	0.7742	1.15	0.3722
Purshia tridentata	0.20	0.6662	0.76	0.4940	1.45	0.2847	0.21	0.8120	0.17	0.8483	0.08	0.9872	0.32	0.8075

* Significant at $\alpha = 0.05$
** Significant at $\alpha = 0.025$
1/ Duncan's Multiple Range Test results for significant main effects are presented in Appendix 6-1.5.
2/ Represents the significance probability (α) associated with F.
3/ Missing values result from insufficient data to produce ANOVA results

ricegrass. However, these differences were not evident in main effects, perhaps because the effect of substrate and mulch were counteracting one another. Whatever the cause might be, it is not likely to be directly related to mulch treatments but rather to competition from other plant species which may have been influenced by mulch and/or seeding regimes at some point in the past.

Cover of planted forb species averaged 14.6 percent over all treatment combinations (Table 6-8), which accounts for approximately 19.7 percent of total mean cover. This represents the highest cover of planted forb species encountered since studies began in 1977. Differences between control and treatment portions of R-3 were slight, with cover averaging 15.8 percent for the control and 13.3 percent on the treatment site (Table 6-7). Highest cover for both control and treatment portions of the plot but was encountered on hydromulched areas which had been seeded at the high rate. Cover of invader forb species (1.1 percent) also differed slightly between both control (0.9 percent) and treatment (1.3 percent) sides of the plot. Cicer milkvetch was the primary contributor of cover for planted species (Appendix 6-1.4). Although yellow sweetcover and Lewis flax were encountered occasionally, their cover during 1983 and 1984 seemed to have decreased relative to previous years. A number of different invader forbs were encountered but no single species stood out as being dominant (Appendix 6-1.4).

Comparison of forb cover for 1984 showed only one significant difference among the treatment combinations, that being based on the substrate x seeding interaction. This difference was not evident based on main effects (Table 6-9). When cover of individual planted forb species was tested no differences were evident (Table 6-10). However, the fact that enough data to complete the ANOVA was present only for Cicer milkvetch illustrates the reduced importance of other species, as noted above. Nevertheless, cover of planted forbs did increase in 1984 probably as a result continued growth of Cicer milkvetch. These data illustrate the success of Cicer milkvetch for revegetation purposes but also show that richness of planted forb species

may be of concern in the long term. If competition from planted grasses, forbs and shrubs continues to be high, cover contributed by invader forbs cannot be expected to fill this void in forb cover. One possible solution to this potential problem would be to use additional forb species which are able to compete with grasses and/or to reduce the seeding rate for grasses.

Cover of planted shrub species averaged 20.2 percent on Plot R-3 during 1984, which accounted for 27.3 percent of the total mean cover (Table 6-8). Cover on the treatment portion of the plot was somewhat higher than on the control, 25.7 and 14.7 percent, respectively. There was considerable variability in cover among the various treatment combinations with the hydromulch-medium seeding combination underlain by processed shale exhibiting the highest overall cover (Table 6-7). Cover of invader shrub species averaged 1.2 percent over all treatments, which represented the highest cover recorded in eight years of study. The highest cover of invader species was found on several treatment combinations within the control area (Table 6-7). Fourwing saltbush and winterfat continue to be the dominant seeded shrub species, with big sagebrush being an important invader and/or species planted as seedlings. Cover of planted shrub species increased in spite of the continued demise of fourwing saltbush which seems to be experiencing die-off among the older individuals. However, because this species produces seed in 3-5 years, it is expected that fourwing saltbush will continue its strong presence on the site.

A statistical comparison of 1984 cover for planted and invader shrub species grouped by growth form indicated a significant difference based on substrate, with higher cover being noted on the portion underlain with processed shale (Table 6-9, Appendix 6-1.5). When cover of individual planted species was compared among treatments, several significant main effect and first order interactions were noted (Table 6-10). Although there was a significant substrate x seeding interaction noted for fourwing saltbush, no main effect differences were significant. The significant substrate x seeding interaction for winterfat did, however, result in a significant main effect difference based on substrate, with cover being higher on the portion of the plot underlain with processed shale. In the

case of rabbitbrush, there was an indication that cover on hydromulched plots was greater than that for areas receiving no mulch. In all likelihood this difference was not a result of cause-and-effect relationships but rather was related to interspecific competition.

b. Precipitation Data - Rainfall at Plot R-3 totalled 15.8 inches for the May-October 1984 period. As noted for Plots R-1 and R-2, the 1984 rainfall was the highest recorded since R-3 was established in 1976. The low precipitation typically experienced during June-July was not evident in 1983 or 1984. Increased average rainfall, combined with more uniformity throughout the growing season, appears to have resulted in increased vegetative growth on R-3. It is unclear why a similar situation was not evident on Plots R-1 and R-2 during 1984.

6.2 MULE DEER HABITAT MODIFICATION STUDY

1. Objectives

During RBOSC's commercial operation, disturbances of the land will result in temporary loss of habitat and forage for wildlife, primarily mule deer. One means of mitigating these losses is to increase the mule deer carrying capacity of undisturbed areas to maintain the overall carrying capacity at, or near, predevelopment levels. RBOSC initiated an experiment in 1980 to determine the feasibility of producing such increases in carrying capacity using the habitat modification techniques described below.

2. Methods

The critical factor which currently limits mule deer populations in the Piceance Creek Basin is the availability of suitable food during periods of heavy snow cover. Thus, a program designed to increase the carrying capacity of local habitats for mule deer should be aimed at increasing suitable forage as well as providing access for mule deer to these modified areas during periods of heavy snow cover. Habitat modification in large, continuous blocks increases wildlife forage, but such large areas commonly fill with snow during periods of heavy snowfall making the area inaccessible to deer. The RBOSC habitat modification program is designed to avoid this problem by modifying vegetation in strips, leaving the vegetation between strips undisturbed. The undisturbed strips provide cover and access routes to the modified areas. The RBOSC study design is discussed in further detail in MDP Monitoring Report Nine (RBOSC 1982). The location of the study site is illustrated in Figure 6-4.

3. Results and Discussion

The mule deer habitat modification study site testing brush removal via rotochopping was sampled for vegetative cover August 21-22, 1984. Data are presented in their entirety in Appendix 6-2.1.

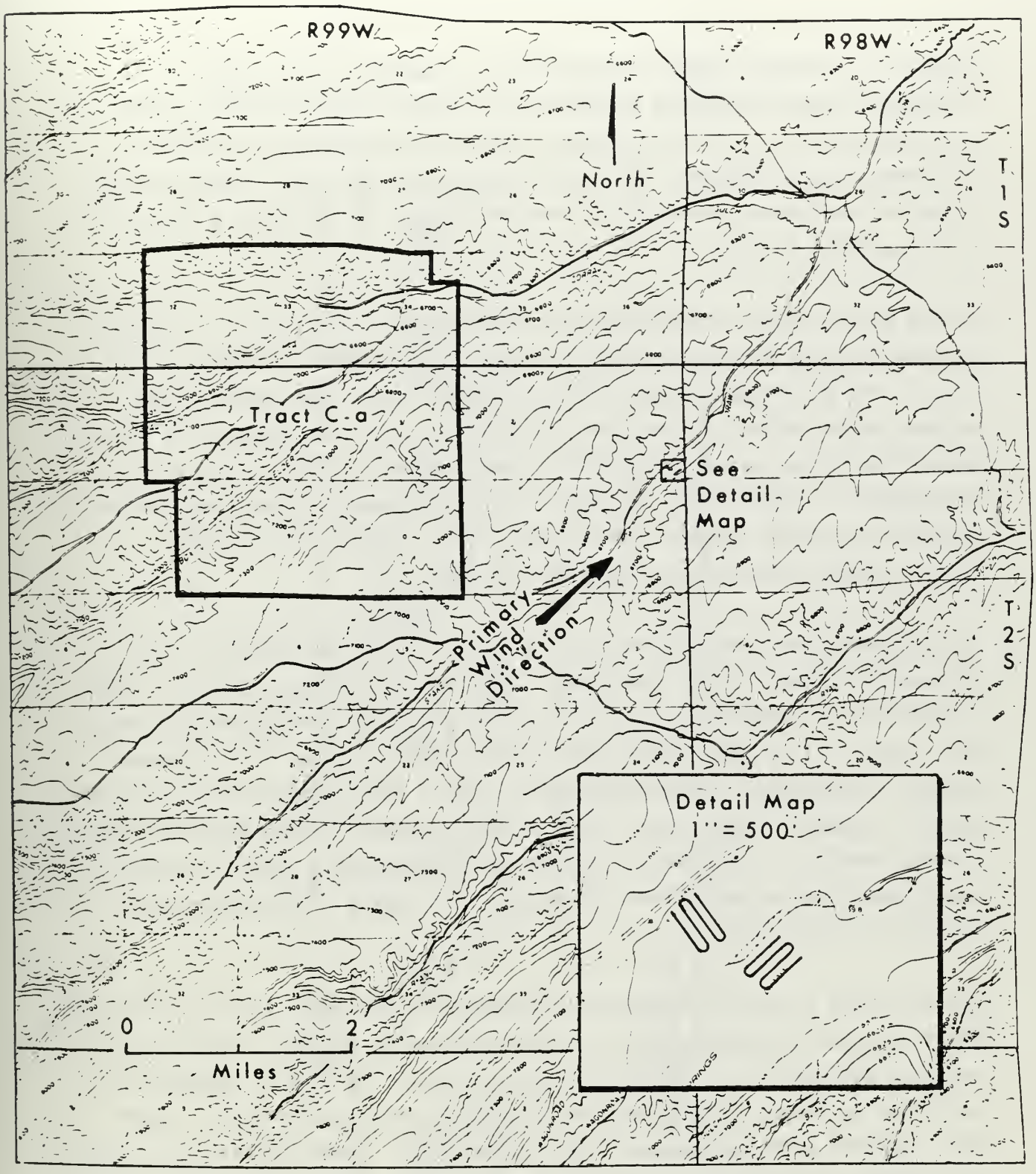


Figure 6-4. Location of Mule Deer Habitat Modification Study

Results of three-way ANOVA's showed that a significant main effect difference based on seeding occurred on the area aligned parallel to the wind (Table 6-11). In this instance, cover was significantly higher on non-seeded areas (Appendix 6-2.2). It is unclear why cover might have been higher on non-seeded areas but it does not appear to have been a function of the treatments tested.

On the area aligned perpendicular to the wind two significant first order interactions and one main effect were noted in the ANOVA results (Table 6-11). The significant fertilizer x chopping interaction seemed to be related to the effect of chopping. The Duncan's Multiple Range Test results showed that cover was significantly higher on areas which had not been rotochopped. ANOVA results for this site also showed a significant effect related to seeding; however, this effect was not evident in Duncan's Multiple Range Test results (Appendix 6-2.2).

The aforementioned results are mixed as to the potential benefits of the treatments tested. After four years, cover on rotochopped portions of the perpendicular oriented area are still lower than the non-chopped portions. Lower cover of the shrub canopy would be expected to allow for increased growth of understory species beneficial to mule deer particularly during the spring. However, lower canopy cover does not appear to have benefited the planted species. Consequently, any increased herbaceous growth consists of non-planted species which have a tendency to be weedy and may not be as beneficial to the deer.

The fact that a similar response to chopping was not noted on the portion of the study area oriented parallel to the wind may be in part a function of moisture availability. The site oriented parallel to wind is adjacent to north-facing slopes and may receive less solar radiation and more runoff than the site oriented perpendicular to the wind. Lower evapotranspiration and greater availability of moisture could have resulted in increased growth within chopped corridors on the parallel as compared to perpendicular corridor orientation.

Table 6-11. Results of Three-way ANOVA's For Arcsine Transformed Cover Estimates for 1984 On Mule Deer Habitat Modification Study Areas.[1/]

Corridor Orientation	Source of Variation: Fertilizer F	Fertilizer PR>F[2/]	Seeding F	Seeding PR>F[2/]	Chopping F	Chopping PF>F[2/]	Fertilizer x Seeding F	Fertilizer x Seeding PF>F[2/]	Fertilizer x Chopping F	Fertilizer x Chopping PR>F[2/]	Seeding x Chopping F	Seeding x Chopping PR>F[2/]	Seeding x Chopping F	Seeding x Chopping PR>F[2/]
Parallel to Wind	0.25	0.6162	7.17**	0.0085	1.25	0.2659	0.01	0.9140	1.19	0.2773	0.20	0.6583	0.00	0.9714
Perpendicular to Wind	0.17	0.6771	4.21*	0.0422	6.10**	0.0147	0.07	0.7902	4.43*	0.0371	0.42	0.5197	2.47	0.1183

* Significant at $\alpha = 0.05$

** Significant at $\alpha = 0.025$

1/ Duncan's Multiple Range Test results for significant main effects are presented in Appendix 6-2.2.

2/ Represents the significance probability (α) associated with F.

The use of fertilizer did not seem to influence cover to any measurable extent. Although there may have been some influence on the palatability of planted and non-planted species in the fertilized portions of the study area, observations of deer use could not confirm this supposition.

These results are inconclusive as to the overall effectiveness of this habitat modification scheme; however, results do indicate that seeded species have not contributed greatly to increased cover. The establishment of seeded species could be enhanced by weed control during the first year after rotochopping. Planting and fertilization during the second year might then be more effective. Further study would be required to ascertain if mule deer actually utilize existing vegetation in the rotochopped corridors to a greater extent than unchopped areas. In any case, brush removal by rotochopping would likely be beneficial only as long as the reduced sagebrush canopy favored understory vegetation. Results of this study show that this length of time depends in part on site conditions, but could be as short as 3-5 years.

6.3 SHRUB GROWTH ENHANCEMENT ON A SIMULATED MINE SITE AND/OR DISPOSAL PILE BENCH

1. Objectives and Rationale

Reclamation of areas disturbed by Tract C-a activities will be accomplished according to a state and federally approved reclamation plan. Reclamation techniques implemented by RBOSC are expected to result in adequate habitat for livestock and wildlife. Additional steps which reduce the amount of time necessary to establish such habitat are desirable. Shrub growth enhancement through water harvesting is an example of one such technique. The objective of this study is to test water harvesting techniques as a means of habitat establishment and enhancement.

In the semiarid environment of the Piceance Basin, increased shrub growth may be achieved by augmenting soil moisture via water harvesting techniques. Water harvesting is a technique designed to conserve and more efficiently utilize normal runoff by concentrating runoff from a large area into a smaller area where it is available for use by plants.

To reduce the potential for soil erosion, benches may be required on slopes resulting from Tract C-a mining and/or disposal activities. To test the influence of increased moisture on shrub growth for wildlife cover, water harvesting techniques are being incorporated into a simulated mine site/disposal pile bench on a southeast-facing slope within Box Elder Gulch on Tract C-a.

2. Methods

The design of the simulated mine site/disposal pile bench is presented in Figures 6-5 and 6-6. Water from accumulated snowpack, runoff from snowmelt, and rainfall should concentrate along the two rows of shrubs on the 6:1 (horizontal:vertical) bench slope (Rows B and C). Increased moisture should also be available to the shrubs in the water bar below the bench (Row E). The rows of shrubs on the 3:1 slope between the bench and the lower water

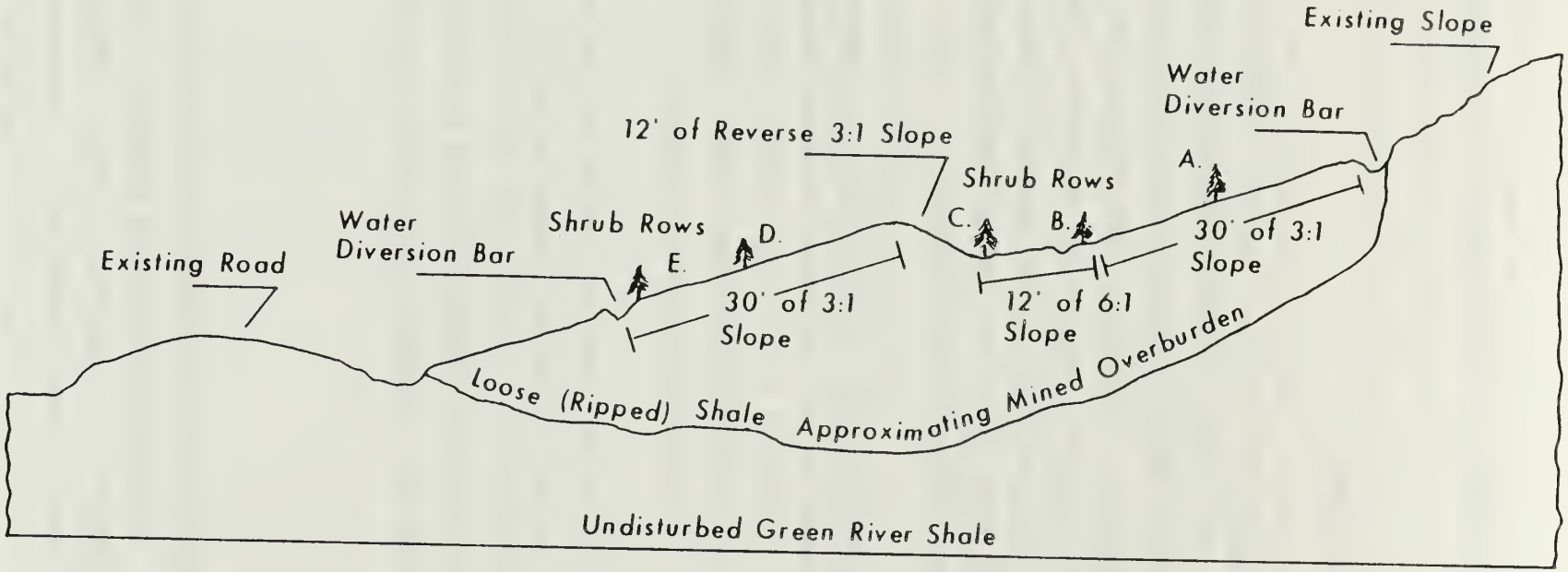


Figure 6-5. Cross Section of Simulated Mine Bench for Testing of Shrub Growth through Water Harvesting.

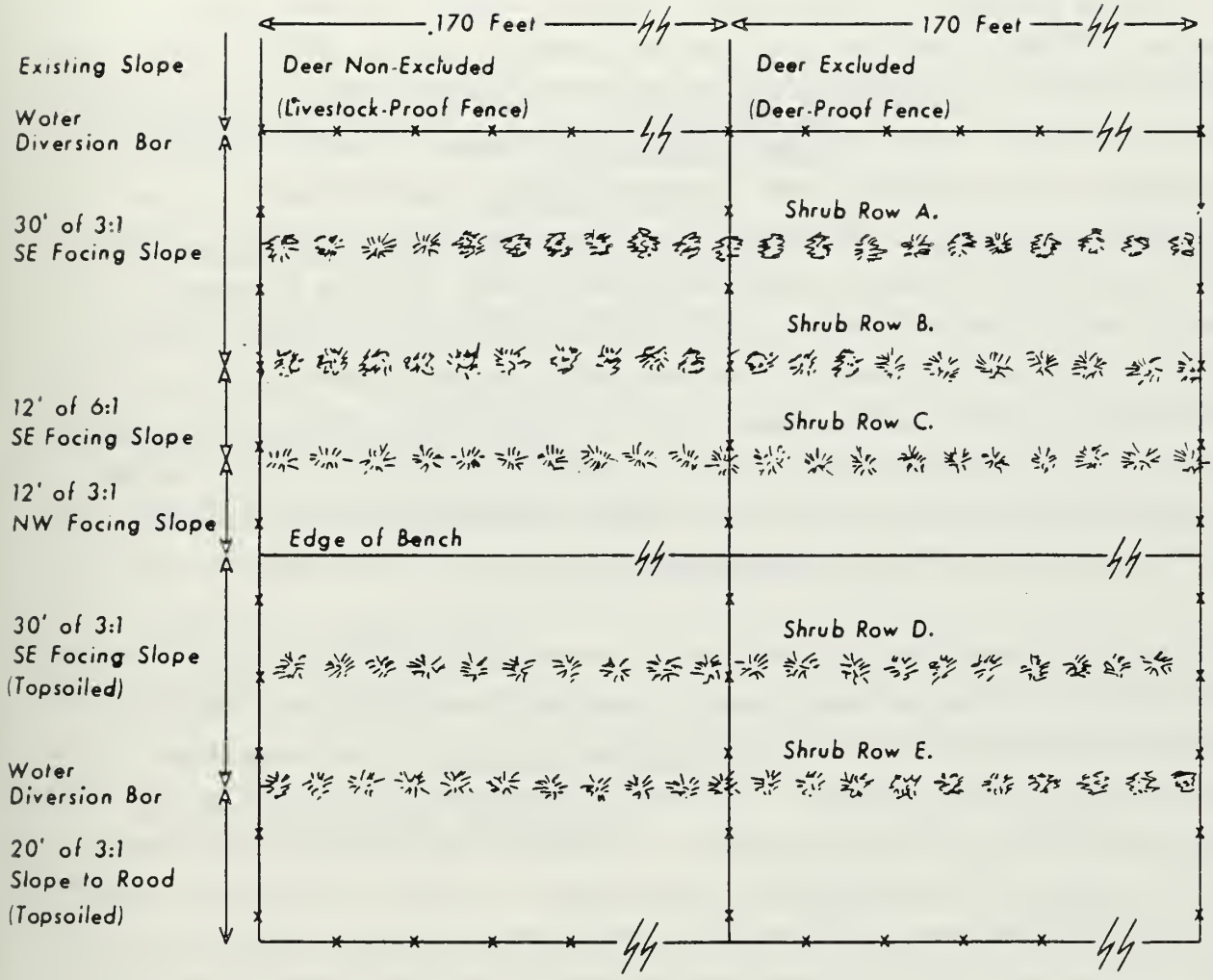


Figure 6-6. Aerial View of Simulated Mine Bench for Testing Enhancement of Shrub Growth through Water Harvesting

bar (Row D), and the row of shrubs above the bench (Row A) serve as controls, where shrub growth without increased moisture will be monitored.

In order to establish wildlife cover rapidly, five of the seven shrub species planted in the test area are not normally used as food by deer: New Mexico foresteria (Foresteria neomexicana), Apache plum (Fallugia paradoxa), New Mexico black locust (Robinea neomexicana), oldman wormwood (Artemisia abrotanum), and Skunkbrush sumac (Rhus trilobata). Serviceberry (Amelanchier alnifolia) and fourwing saltbush (Atriplex canescens), choice deer food, were included to test the effect of deer browsing pressure on shrub growth. One-half of the test is fenced to exclude deer and cattle, and the other half is fenced to exclude cattle but allow deer entry. All shrub species were planted as tublings in June of 1982. Shrubs were watered at the time of planting and irrigated as necessary during the first summer to ensure establishment. All areas between shrub rows were planted with the RBOSC seed mixture illustrated on Table 6-12.

It should be noted that two individuals of each of the shrub species - serviceberry, oldman wormwood, Apache plume and skunkbrush sumac were planted at each designated location in Rows B and C to insure adequate survival for testing purposes. The weaker individual was removed at the beginning of the 1984 growing season. It should also be noted that these species were of greenhouse stock, eight months old; that individuals of the fourwing saltbush were of uneven age, from eight to eighteen months; and, that the New Mexico black locust and New Mexico foresteria were 18 months old at planting.

The ultimate goal of harvesting water to enhance shrub growth on the simulated mine bench test is to provide vegetation cover for deer within four years. In the Piceance Basin, this cover is necessary for thermal protection and predator avoidance. This cover is normally provided by pinyon-juniper forests, tall sagebrush in bottom lands and other areas of tall, dense vegetation. At the onset of this test, it was decided that a shrub height of four feet (ca 120 cm) would be the lower limit of adequate cover for mule deer. A similar sized diameter was also considered important

Table 6-12. Seed Mixture Used in Final Reclamation by RBOSC.

Plant Species	Seeding Rate (Kg/Ha)
Pubescent Wheatgrass (Agropyron trichophorum)	3.0
Western Wheatgrass (Agropyron smithii)	4.2
Streambank Wheatgrass (Agropyron riparium)	2.4
Indian Ricegrass (Oryzopsis hymenoides)	1.8
Green Needlegrass (Stipa viridula)	1.8
Smooth Brome (Bromus inermis)	1.8
Cicer Milkvetch (Astragalus cicer)	1.8
Yellow Sweetclover (Melilotus officinalis)	0.9
Lewis Flax (Linum lewisii)	1.2
Winterfat (Ceratoides lanata)	1.2
Fourwing Saltbush (Atriplex canescens)	1.2
Bitterbrush (Purshia tridentata)	1.2
TOTAL	22.50

for each shrub. Because the seven species of shrubs used in the test have different growth rates and physiognomy, it was necessary to compare shrub growth performance by a common index. A plant height - plant diameter (PH-PD) index was developed, as derived by the following formula:

$$\text{PH-PD} = \frac{\frac{\text{Shrub Height (cm)}}{120\text{ cm}} + \frac{\text{Shrub Diameter (cm)}}{120\text{ cm}}}{2}$$

This index provides information on how well shrubs in the various treatments on the simulated mine bench achieve the lower limit of adequate cover (120 cm). This lower limit will be reached when the PH-PD index is equal to one.

Shrub measurements (plant height and diameter) of each individual are made on a monthly basis during the growing season. These data are then used in determining the PH-PD index. Plant mortality was also noted each month.

In order to test the effectiveness of the water harvesting technique, moisture content is normally measured monthly during the growing season within the soil profiles on control and treatment portions of the simulated bench. Permanently placed soil access tubes allow for repeated soil moisture determinations at the same locations using the Troxler Depth Moisture Gauge. Because of gauge malfunctions, moisture determinations were not made during 1984.

Success of revegetation efforts between shrub rows (those areas seeded with species listed on Table 6-12) is monitored along permanently established transects within treatment areas. Transects are placed during the first growing season after planting and are marked at both ends with stakes. Aluminum marking tags identifying the transect number, as well as the beginning and/or end of the transect, are attached to these stakes. Transects are 40 m in length and are oriented perpendicular to the existing slope.

Cover of grasses, forbs and shrubs is estimated annually within sampling frames (1 m^2) placed at five-meter intervals along the transects. A meter tape stretched between the stakes at either end of the transect allows exact placement of these frames. Sampling frames are subdivided into 5 percent segments and cover of individual species is estimated to the nearest one percent. All are recorded on field data forms, which are formatted for direct computer entry.

3. Results and Discussion

a. Shrub Survival - Percent survival of all shrub species by treatment is presented in Table 6-13. From this table it can be seen that different shrub species and different treatments exhibited varying survival rates.

Serviceberry, fourwing saltbush, New Mexico foresteria and skunkbrush sumac had some mortality during the year with a lower percent survival than in 1983. The lowest overall survival was again exhibited by serviceberry, and this survival percentage was markedly enhanced by the double plantings in Rows B and C. Serviceberry is probably not a suitable species for reclaiming southeast-facing slopes at 6,800 feet elevation.

Fourwing saltbush appeared to exhibit a general decline in survival rate. Although some of the plants continued to grow well (see Section b. Shrub Growth), fourwing saltbush had the highest mortality of all shrubs during the 1984 season. It appears that cold, dessicating winters are deleterious to survival of fourwing saltbush (D. McArthur personal communication) and individuals of this species may not be expected to live as long as those of other species in the climate of this area. However, fourwing saltbush matures and produces seed sooner than other shrubs and populations of fourwing may not be affected by the short life span of individuals.

It is unknown why the New Mexico foresteria and skunkbrush sumac suffered mortality. Higher mortality of these two species occurred where deer had access for browsing and this may have been a factor.

Table 6-13. Percent Survival of all Shrub Species by Treatment on the Simulated Mine Bench Test in September 1984 after Three Growing Seasons.

	Deer Excluded Row						Deer Not Excluded Row					
	A	B	C	D	E	Ave.	A	B	C	D	E	Ave.
Amelanchier alnifolia	33	50	67	33	33	43	0	43	83	0	0	25
Artemisia abrotanum	100	80	100	67	33	76	100	100	100	50	83	87
Atriplex canescens	1/	57	100	100	50	77	-	0	17	71	0	22
Fallugia paradoxa	-	100	100	-	-	100	-	60	83	-	-	71
Foresteria neomexicana	-	100	100	67	83	87	-	100	100	83	100	96
Rhus trilobata	83	100	100	100	17	80	67	100	100	33	17	63
Robinea neomexicana	-	100	100	-	-	100	-	100	100	-	-	100
AVERAGE	72	70	95	73	43	80	56	72	83	48	40	66

1/ - Indicates no shrubs of a particular species were planted in that treatment.

The only species with 100 percent survival was New Mexico black locust. This species did experience die back due to freezing but managed adequate regrowth during the summer.

The effects of excluding deer from browsing on the shrubs appears noticeable for some species and not for others. For instance, the percent survival of serviceberry and fourwing saltbush, palatable to deer, were substantially lower where deer had access for browsing. The survival of oldman wormwood was somewhat lower in the deer excluded portion of the test. This species is not considered palatable to deer but is highly palatable to rodents and rabbits. Rabbit use of oldman wormwood was very noticeable during the winter of 1983/84 and probably had an effect on survival.

As in 1983, the row with the highest overall survival was Row C. This row is located at the interface of the 6:1 southeast-facing bench slope and the 3:1 northwest-facing reverse grade slope. This area has a deep (18-24 in.) snowpack during the winter and is somewhat sheltered from the southwest-trending winds. It is unknown if more moisture was available for the shrubs in this row in 1984. The soil moisture test for 1983 showed that Row C had less moisture during the growing season than did other rows in the test. Increased survival along Row C may be attributable to shrub protection by this snowpack and the reverse grade slope.

As in 1983, the lowest shrub survival was in Row E, the waterbar/topsoil treatment. Shrubs in this row experienced considerable additional mortality since the 1983 survey. Potential factors causing this mortality were outlined in MDP Environmental Report 13 (RBOSC 1984).

b. Shrub Growth - Means of the PH-PD index, a measurement of overall growth attainment, for each shrub species by row and fence treatments for September 1984 are presented in Table 6-14. Greater overall plant growth is represented by larger numbers in this Table. Individual shrub measurements for September 1984 are presented in Appendix 6-3.1.

Table 6-14. Means of the Plant Height-Plant Diameter (PH-PD) Index for Each Shrub Species by Treatment on the Simulated Mine Bench Test in September 1984 after Three Growing Seasons.

	Deer Excluded Row						Deer Not Excluded Row					
	A	B	C	D	E	Ave.	A	B	C	D	E	Ave.
Amelanchier alnifolia	.19	.24	.15	.09	.15	.16	0	.22	.19	0	0	.21
Artemisia abrotanum	.46	.40*	.42	.29	.60*	.43	.47	.27*	.45	.30	.41*	.38
Atriplex canescens	-1/	.68	.86	1.00	.99	.88	-	.74	1.01	0	0	.88
Fallugia paradoxa	-	.50*	.40	-	-	.45	-	.35*	.48	-	-	.42
Foresteria neomexicana	-	.37	.38	.30*	.39*	.36*	-	.32	.35	.25*	.21*	.28*
Rhus trilobata	.41	.34*	.35	.18*	.62*	.38*	.35	.30*	.30	.25*	.23*	.29*
Robinea neomexicana	-	.75*	.78	-	-	.77*	-	.50*	.68	-	-	.59*
AVERAGE						.49						.44

1/ - Indicates no shrubs of a particular species were planted in that treatment.

* - Significantly different at the P=0.05 level of probability between deer exclusion treatments within a given row.

Overall shrub growth appeared greater in almost all treatments in 1984 over 1983. The 1984 growing season was favorable for plant growth due to higher than normal precipitation, and increased shrub growth would be expected. Those species with substantial increased growth were Apache plume, fourwing saltbush and New Mexico black locust.

Noticeable, and sometimes significant, differences were apparent within some species when comparing the fencing treatments within a given row treatment. In general, the shrubs were larger where deer did not have access for browsing. However, the degree of palatability of the species did not seem to influence the overall growth. Palatable as well as non-palatable species were larger where deer did not have access. As noted in the 1983 MDP Environmental Report, even shrub species not usually chosen as food by deer will be browsed as deer "test" for palatability. This limited browsing may have an effect on shrub growth when the shrubs are small. Also, non-palatable shrubs may not possess the ability to grow rapidly after browsing that other more highly browsed species do. It is also possible that some shrub growth conditions, such as soil type, may be different between the two fencing treatments.

During the design of the test it was determined that adequate cover for deer would be attained when shrub species reached a growth attainment index of one. The shrub with the highest growth attainment index was fourwing saltbush. This species, after three growing seasons in the field, has nearly attained the desired index of one. The growth habit of fourwing saltbush is rather wide spreading and low of stature. Due to the high mortality of this species, it is uncertain if fourwing saltbush would be suitable for providing cover over a long period. Certainly it would be important in establishing cover early while other shrubs are still growing.

As in 1983, the other shrub species with a high growth attainment index was New Mexico black locust. This species was set back two years in succession by frost damage but still managed to attain substantial growth. It is, however, an introduced species and may not be suitable for inclusion in a plant mixture for reclamation in northwest Colorado.

Other species which show promise for planting to provide cover are Apache plume and skunkbrush sumac. Individuals of both of these species were younger at the time of planting than those of fourwing saltbush and New Mexico black locust and would be expected to exhibit a lower growth index at this stage in their growth.

c. Reclamation Success - Cover estimates for species occurring on the simulated mine bench test were made on October 3, 1984. These data are summarized by treatment in Table 6-15 and are presented in their entirety in Appendix 6-3.1.

Total mean cover was no different between the deer excluded and deer not excluded fencing treatments even though deer fed heavily where they had access in the Spring of 1984. Apparently, this feeding for a short time early in the growing season can be overcome by plant growth during the summer. Three species did show less cover where deer had access. These species were smooth brome, fourwing saltbush and shadscale saltbush - all preferred forage species. Lewis flax and wheatgrass species had slightly higher cover where deer were permitted to forage.

As expected, total mean cover was greater on treatments with topsoil covering than on treatments with no topsoil. However, three species - Indian ricegrass, smooth brome and cicer milkvetch - had higher percent cover on the no topsoil treatment than on the treatment with topsoil. It should be noted that weathering of the Green River shale, of which the bench test is composed, is producing a soil-like material with a high percentage of fine grained particles. Subsequent sampling should determine the suitability of this material as a plant growth medium.

Table 6-15. Comparison of Mean Cover (%) of Planted and Invaded Species among Treatments on the Simulated Mine Bench Test in October 1984.

	Treatment			
	Deer Excluded		Deer Not Excluded	
	Topsoil	No Topsoil	Topsoil	No Topsoil
Planted Species				
Wheatgrass spp.	21.0	13.0	24.4	14.3
Indian Ricegrass	0.4	1.4	0.5	1.5
Green Needlegrass	0.0	0.0	0.1	0.1
Smooth Brome	4.3	6.9	2.6	4.5
Cicer Milkvetch	0.9	1.8	1.9	4.4
Yellow Sweetclover	0.4	0.0	0.4	0.1
Lewis Flax	7.4	4.8	9.5	6.6
Winterfat	0.0	0.0	0.0	0.0
Fourwing Saltbush	2.8	0.1	0.5	0.5
Bitterbrush	0.0	0.0	0.0	0.0
Invaded Species				
Cheatgrass Brome	0.0	0.1	0.0	0.0
Russian Thistle	0.1	0.1	0.0	0.1
Halogeton	0.1	0.5	0.0	0.0
Shadscale Saltbush	3.3	0.3	0.0	0.4
Total Mean Cover	40.7	29.0	39.9	32.5

6.4 STUDY TO ALTER NATURAL SUCCESSION AFTER FIRE FOR ENHANCED DEER-LIVESTOCK FORAGE

1. Objective and Rationale

During RBOSC's commercial operation, disturbance of land will result in temporary loss of forage for wildlife, including mule deer, and for livestock. One means of mitigating these losses is to increase the amount of available forage in undisturbed areas thereby maintaining carrying capacity in the area at, or near, predevelopment levels. A factor important to wintering mule deer is the availability of quality green forage early in the spring. Spring "green-up" time is a period during which deer begin to recoup body nutrients lost throughout the winter. In the spring, deer congregate in large numbers in hay fields and meadows where a high density of newly emerged plant sprouts occurs. This critical forage area for deer is also an important summer grazing area for livestock.

Many creek bottoms in the vicinity of Tract C-a are covered with rank sagebrush, rabbitbrush and greasewood, and serve as wintering areas for wildlife. If a very small percentage of these bottoms were converted into areas providing quality forage for spring "green-up" and summer grazing, the carrying capacity of the region might be increased.

The use of fire to "set back" plant succession and to remove undesirable plant species is quite common (Wright et al, 1979). However, succession after several natural fires in Yellow Creek and Duck Creek northeast of Tract C-a has not resulted in vegetation more suitable for wildlife in these areas. RBOSC initiated an experiment in 1982 to determine the feasibility of producing such increases using the habitat modification techniques as described in MDP Monitoring Report 11 and 13 (RBOSC 1983, 1984). This study site was not monitored during 1984. Future monitoring of this site will follow the approved Scope of Work.

6.5 COMPARISON STUDY OF INHALABLE AND TOTAL SUSPENDED PARTICULATES

1. Objectives and Rationale

Many investigations have shown that the range of particle sizes measured in the current National Ambient Air Quality Standard for Total Suspended Particulates (TSP) do not directly address health-related concerns. The major reason for this is that particles collected by TSP monitors have diameters up to a maximum of approximately 30-50 um, whereas particles with diameters larger than 10 to 15 um are excluded from the body by natural defense mechanisms in the respiratory system. At the same time, the larger particles have an inordinately large influence on a gravimetric sampling technique such as used for TSP, since the mass of a particle is generally proportional to the third power of the radius of a particle.

As a result, EPA is currently in the process of changing the present TSP standard to a more health-related inhalable particulate standard. The new standard has been proposed with a 50 percent particle cutpoint (or rejection point) at 10 um, and will be referred to as PM_{10}. The American Mining Congress (AMC) has proposed an alternative PM_6 standard, which has a 50 percent particle cutpoint at 6 um.

In order to determine the impact of a possible new standard on our permitting activities, and to be able to intelligently comment on the proposed regulations, PM_{10} monitors were installed at the existing sites toward the end of 1982. In addition, a PM_6 monitor, specially designed and built for the AMC, was installed in October 1983.

2. Methods

One PM_{10} monitor was colocated with each of the existing TSP monitors at Sites 1 and 3. These PM_{10} samplers are standard Hi-Vol monitors modified with a Wedding PM_{10} inlet. A PM_6 monitor, fitted with a specially designed Wedding PM_6 inlet, was also colocated at Site 1.

3. Results and Discussion

The TSP, PM_{10} and PM_6 data for 1984 are listed in Table 6-16. The geometric means, arithmetic means and maximum concentration for each season and for the year are presented in Table 6-17. The highest, second highest concentration of 40 ug/m^3 during 1984 was recorded by the TSP monitor at Site 3. This is far below the 24-hr secondary NAAQS of 150 ug/m^3. The annual average concentrations are also quite low, with a maximum geometric mean of 8 ug/m^3 and a maximum arithmetic mean of 11 ug/m^3, both recorded at Site 3.

As a comparison, the second highest 24-hr concentrations of the TSP, PM_{10}, and PM_6 during 1984 at Site 1 were 26, 12, and 10 ug/m^3, respectively. The annual geometric means for PM_{10} at Sites 1 and 3 are 57 and 53 percent, respectively, of the annual geometric means for TSP at the same sites. Similarly, the annual arithmetic means for PM_{10} are 51 and 48 percent at Sites 1 and 3, respectively, of the annual arithmetic means for TSP. The geometric and arithmetic means of PM_6 at Site 1 are 41 and 37 percent of the respective means of TSP at Site 1. In all cases, the arithmetic average (proposed in EPA regulations) is higher than the geometric average. The increase in the annual arithmetic mean over the geometric mean is moderate for TSP data (a 3 ug/m^3 increase for both sites), and low for the inhalable particulate data (no more than 1 ug/m^3).

Figure 6-7 presents the distribution of TSP, PM_{10} and PM_6 concentrations during 1984. The figure shows that PM_6 has the lowest range of concentrations (0-11 ug/m^3, with a mode of 3 ug/m^3), followed by PM_{10} (0-13 ug/m^3, with a mode of 4 ug/m^3) and TSP (0-28 ug/m^3, with a mode of 5 ug/m^3). Perhaps the most striking aspect of the data evident in the figure is the distinct differences in the distributions of the data -- the PM_{10} and PM_6 data have a fairly tight distribution that is roughly symmetrical around the mode, while the TSP distribution is strongly skewed toward higher concentrations. The higher TSP concentrations on the extended tail of the distribution may be related to the well-known sampling problems with the TSP inlet, such as inlet efficiency changes with changes in wind speed and direction. The skewed TSP distribution also explains why th:

TABLE 6-16. INHALABLE AND TOTAL SUSPENDED PARTICULATE CONCENTRATIONS FOR 1984

	SITE1			SITE3	
DATE	TSP	PM-10	PM-6	TSP	PM-10
03JAN84	2	2	1	1	1
07JAN84	2	3	2	0	0
11JAN84	6	4	3	2	1
15JAN84	8	•	6	6	5
19JAN84	5	4	3	3	1
23JAN84	4	3	2	2	1
27JAN84	2	1	0	6	0
31JAN84	3	2	1	4	1
04FEB84	5	5	5	•	3
08FEB84	3	5	4	5	3
12FEB84	2	2	2	3	1
16FEB84	0	2	1	4	2
20FEB84	7	4	4	4	3
24FEB84	2	4	3	6	4
28FEB84	10	6	5	5	4
03MAR84	5	4	4	7	5
07MAR84	6	4	4	4	3
11MAR84	4	5	3	5	3
15MAR84	15	3	2	3	3
19MAR84	•	•	•	4	2
23MAR84	1	4	4	4	2
27MAR84	2	2	1	2	1
31MAR84	1	4	4	5	3
04APR84	11	6	6	5	4
08APR84	12	2	6	11	4
12APR84	7	3	2	5	2
16APR84	4	4	5	10	4
20APR84	1	3	3	5	3
24APR84	12	9	3	12	7
28APR84	7	4	3	5	2
02MAY84	6	3	2	7	5
06MAY84	10	4	3	9	5
10MAY84	23	11	10	26	12
14MAY84	26	•	11	28	10
18MAY84	22	12	8	27	13
22MAY84	12	9	5	19	8
26MAY84	15	7	4	24	9
30MAY84	25	9	7	31	12
03JUN84	20	7	5	18	9
07JUN84	7	8	2	4	7
11JUN84	15	7	4	16	•
15JUN84	26	10	8	22	7
19JUN84	21	9	6	18	16
23JUN84	17	8	6	15	7
27JUN84	25	11	8	25	12
01JUL84	14	9	6	15	11

TABLE 6-16. INHALABLE AND TOTAL SUSPENDED PARTICULATE CONCENTRATIONS FOR 1984

DATE	SITE1 TSP	SITE1 PM-10	SITE1 PM-6	SITE3 TSP	SITE3 PM-10
05JUL84	15	6	5	26	8
09JUL84	16	9	5	16	7
13JUL84	25	8	6	24	8
17JUL84	23	9	7	40	16
21JUL84	22	7	5	22	8
25JUL84	9	4	2	11	10
29JUL84	10	5	4	•	•
02AUG84	8	4	2	•	•
06AUG84	15	4	7	16	8
10AUG84	17	7	4	15	8
14AUG84	6	3	1	9	5
18AUG84	13	7	4	12	11
22AUG84	7	3	3	9	4
26AUG84	18	5	3	10	5
30AUG84	26	8	5	•	29
03SEP84	•	12	2	16	6
07SEP84	21	5	•	41	13
11SEP84	10	4	1	17	6
15SEP84	17	5	4	16	8
19SEP84	10	4	2	11	5
23SEP84	24	9	4	20	7
27SEP84	10	5	3	12	6
01OCT84	5	8	1	6	3
05OCT84	12	5	4	10	5
09OCT84	10	13	3	13	5
13OCT84	1	1	•	3	0
17OCT84	5	0	3	5	•
21OCT84	5	4	1	4	•
25OCT84	9	7	5	9	6
29OCT84	7	6	3	9	4
02NOV84	20	9	6	24	11
06NOV84	•	•	•	•	4
10NOV84	5	2	1	3	0
14NOV84	8	2	1	7	1
18NOV84	13	7	5	7	5
22NOV84	6	1	3	5	4
26NOV84	4	2	1	2	1
30NOV84	5	1	1	1	0
04DEC84	9	6	6	5	4
08DEC84	1	0	1	2	0
12DEC84	•	•	•	1	•
16DEC84	6	3	2	7	2
20DEC84	5	3	9	4	3
24DEC84	3	1	•	5	•
28DEC84	3	3	3	13	3

Table 6-17. Quarterly and Annual Means (Geometric and Arithmetic) and Maximum Values of 24-Hour Average TSP, PM_{10} and PM_6 Concentrations (ug/m^3) Based on Fourth-Day Sampling During 1984 on Tract C-a.

	Site 1			Site 3	
	TSP	PM_{10}	PM_6	TSP	PM_{10}
Winter 1984 (Jan., Feb., Dec.)					
Geometric Mean	3.4	2.8	2.4	3.5	1.7
Arithmetic Mean	4.3	3.3	3.2	4.3	2.1
Spring 1984 (Mar.-May)					
Geometric Mean	7.3	4.6	3.9	8.2	4.3
Arithmetic Mean	10.4	5.3	4.5	11.2	5.4
Summer 1984 (June-Aug.)					
Geometric Mean	14.9	6.5	4.2	15.3	8.8
Arithmetic Mean	16.3	6.9	4.7	17.1	9.8
Fall 1984 (Sept.-Nov.)					
Geometric Mean	7.8	3.8	2.3	7.8	3.4
Arithmetic Mean	9.8	5.2	2.8	10.9	4.8
1984 Annual					
Geometric Mean	7.5	4.3	3.1	7.6	4.0
Arithmetic Mean	10.3	5.2	3.9	11.5	5.5
Maximum	28	13	11	41	29
2nd Maximum	26	12	10	40	16

difference in the arithmetic and geometric means of the TSP data than the PM_{10} and PM_6 data (since the arithmetic mean weights extreme values in the distribution more heavily than the geometric mean).

Table 6-18 presents correlation coefficients and coefficients of determination for the TSP, PM_{10} and PM_6 1984 data sets. Two of the highest correlations were between the TSP and PM_{10} monitors at Site 1 and Site 3 (0.76 and 0.87, respectively). Thus, the variation of the TSP data was associated with between 58 and 76 percent of the PM_{10} data at the same site. The Site 1 TSP and PM_6 data were slightly less correlated (0.72) than the TSP and PM_{10} data. The lowest correlation (0.63) was between the Site 1 PM_{10} and PM_6 data, which is somewhat surprising since the monitors were colocated and use an inlet with a similar design. One possible reason for this lower than expected correlation may be the uncertainty inherent in the low inhalable particulate concentrations found during the six months in which a snowcover is usually present.

Table 6-18. Correlation Coefficients (r) and Coefficients of Determination (r^2) for the 24-hour Average TSP, PM_{10} and PM_6 Data During 1984, Tract C-a.

Monitors/Sites Being Correlated	Correlations r	r^2	n
Site 1 TSP and Site 1 PM_{10}	0.76	0.58	85
Site 1 TSP and Site 1 PM_6	0.72	0.52	84
Site 1 PM_{10} and Site 1 PM_6	0.63	0.39	83
Site 1 TSP and Site 3 TSP	0.86	0.73	87
Site 1 PM_{10} and Site 3 PM_{10}	0.65	0.42	80
Site 3 TSP and Site 3 PM_{10}	0.87	0.76	81

6.6 EFFECTS OF SURFACE DISCHARGE ON THE ALLUVIAL AQUIFER

1. Objectives and Methods

Discharge of water to surface streams could influence water levels in the alluvial aquifer downgradient from Tract C-a. To assess possible effects of surface discharge alluvial wells were monitored. The following evaluation of past discharges was requested by the BLM/OSPO to examine the potential effects of surface discharges of mine/aquifer water during MIS retort abandonment.

2. Results and Discussion

Alluvial wells were monitored during a pump test in 1978 to determine the impact of discharge from mine dewatering on water level and quality in the alluvial aquifer downgradient from Tract C-a (RBOSC 1979b). The following wells were monitored:

GS-S11, -S11A - Corral Gulch, 2 miles downstream from the east tract boundary.

GS-S24 - Corral Gulch, 3 miles downstream from the east tract boundary.

GS-S27, -S27A - Corral Gulch, at the east tract boundary.

During the first quarter of 1978, the total average discharge into Corral Gulch was 43 million gallons or 133 acre feet of water. The average monthly discharge before, during and after the pump test was as follows:

	Million Gallons	Acre Feet
April	72	220
May	89	270
June	95	290

During the third quarter of 1978, total average discharge dropped to 55 million gallons or 170 acre feet of water.

The water levels of GS-S11A (both deep and shallow completions) rose sharply in May as a result of the combined effect of the dewatering discharge and spring snowmelt. The shallow completion returned to its baseline level in late May even though surface discharges continued. The deep completion rose from a mean depth to water of 57 feet in March 1978 to a mean of 50 feet from May to the end of 1978. This water level never returned to baseline levels, exhibiting normal seasonal fluctuations through 1980, after which the well was not monitored. Well GS-S11 deep exhibited almost identical water level changes as GS-S11A deep, with a rise in May, corresponding to the discharge and no corresponding decline with the cessation of discharge. It was determined that the lack of decline in all probability was the result of the aquifer's relatively low permeability and the associated lag-time for any major response (RBOSC 1979).

Conductivity values in GS-S11A deep dropped from an average of 1,800 umhos/cm to 1,400 umhos/cm in May and June and then rose to an average of 2,000 umhos/cm from July through the remainder of 1978. Conductivity observations of GS-S11D during and after the pump test were consistent with baseline observations.

The water level in GS-S24 rose from an average depth to water of 10.7 feet in April to 7.4 feet in May and 6.3 feet in June. The water level remained elevated until 1981 when it returned to an average of 9.2 feet. It should be noted that the baseline water level of this well (1975-1977) fluctuated from 5.2 feet to 11.6 feet. Conductivity values dropped only slightly in May and then returned to baseline observations.

The water level of GS-S27A rose in late May but dried up after July. This well does not typically contain water at present. The water level of GS-S27S rose sharply during the pump test and spring snowmelt from an average depth to water of 15 feet in March to 6 feet in April and then to 5 feet in May. The water level returned to baseline measurements later in

1978, and lower than baseline in 1979. Conductivity values were consistent with baseline.

Water chemistry samples from GS-S27S were collected during the pump test. The results indicated that as water level rose, calcium and fluoride decreased, while bicarbonate, magnesium and DOC increased. These variations were not extreme.

Data were collected from wells farther downstream in Yellow Creek and these data indicated stable conditions during the pump test due to their distant location from tract operations.

Analysis of variance comparing 1978 and all other report years for the alluvial aquifer show that 1978 was not significantly different from all other years for chloride and fluoride and, conversely, 1978 was significantly different from all years for bicarbonate and sodium. The 1978 pH and sulfate means were variable only with years since the pump test. All other major parameters considered were variable before, during and after the 1978 pump test. These ANOVA results can be seen in Appendix 5-1.4.

During the 1979 Surface Induced Recharge (SIR) test, excess water was discharged into Corral Gulch (RBOSC 1980). This water was discharged February 23 through September 16. Average discharge before, during and after this test was as follows:

	Million Gallons	Acre Feet
January	39	118
February	45	139
March	92	282
April	81	248
May	79	242
June, July, August	160	490
September, October, November	94	288

The alluvial wells previously listed were monitored during this period. The water level of GS-S27 dropped 16 feet between March and September 1979, not correlated with changes in discharge, and it was unclear why the level changed. Field water quality parameter remained unchanged.

Wells GS-S11 and GS-S11A (2 miles downstream) responded to changes in discharge and spring recharge. Water levels rose slowly after the discharge to Corral Gulch increased in February, but increased sharply in May and began a slow decrease in June after the SIR test and spring recharge was over. The water levels remained low after the termination of the SIR test in September. The conductivity in the shallow wells increased with the rise in water levels, but also increased when the water levels continued to decline in the fall. The conductivity in the deeper wells fluctuated randomly with an increasing trend throughout 1979. The pH in all the wells was fairly constant throughout the year.

Well GS-S24 (3 miles downstream) did not respond to increased discharge in February but showed a sharp response to spring recharge. Conductivity showed a decrease in late summer and early fall which may have been due to the presence of fresh water following spring run-off. Fluctuation in pH occurred, but no long-term changes were apparent.

Analysis of variance comparing 1979 with all other report years for the alluvial aquifer shows that 1979 was not significantly different from all other years for chloride, fluoride and calcium. 1979 differed from only one or two years for TDS, alkalinity and magnesium, while all other major parameters were highly variable among years. These analyses can be seen in Appendix 5-1.4.

Surface discharge into Corral Gulch also occurred during 1980, from May through mid-June and in August. The May through mid-June discharge totalled 36 million gallons (101 acre feet), while the August discharge totalled 6 million gallons (18 acre feet).

The water level in well GS-S27 rose steadily from late 1979 through May 1980 and then declined slowly through November 1980. Conductivity was variable during 1980 with peak levels in August and September 1980. The pH observations showed no seasonal pattern.

The water level of well GS-S24 declined from November 1979 through May 1980. During June, the water level rose to the yearly peak in early July and then declined steadily through the end of 1980. This was probably a response to the natural runoff-recharge cycle and was similar to the pattern observed in 1979. No seasonal pattern was observed for conductivity or pH.

Analysis of variance comparing 1980 with all other report years for the alluvial aquifer shows that 1980 was not significantly different from all or most other years for calcium, fluoride, chloride and alkalinity. 1980 differed from most other years for TDS, conductivity, bicarbonate and sulfate. These analyses can be found in Appendix 5-1.4.

Data collected during these discharge periods can be found in more detail in RBOSC MDP Monitoring Reports 3, 5 and 7 (RBOSC 1979b, 1980, 1981).

The primary impact of the discharge of dewatering water is to raise the water level in the alluvium and even out seasonal fluctuations. Water

levels in the Corral Gulch alluvial wells recently monitored are fairly high (at or higher than baseline) including the GS-S28 wells 6-1/2 miles down Yellow Creek. This is due to saturation of the alluvium after heavy snowmelt in 1982 and 1983.

6.7 RUN-OF-MINE LYSIMETERS

1. Objectives and Methods

The run-of-mine lysimeters objectives and methods are described in RBOSC MDP monitoring report 11 (RBOSC 1983).

2. Results and Discussion

The 5, 10 and 15 foot lysimeters were monitored from August through October 1984 for leachate volume and conductivity. Total monthly volumes (liters) and mean conductivity data (micromhos per cm) are shown for each collector:

	5 Foot		10 Foot		15 Foot	
	Total Liters	Average umhos/cm	Total Liters	Average umhos/cm	Total Liters	Average umhos/cm
August	19	8,260	>113	17,500	48	21,000
September	4	8,750	22	20,250	4	22,750
October	5	7,450	>69	19,250	6	22,250

Mean conductivity of the leachate increases directly with raw shale depth. The 1984 conductivity means are appreciably less than the 1983 means, which were 15,150, 28,050 and 27,350 umhos/cm for the 5, 10 and 15 foot collectors, respectively. This would indicate that raw shale leachate water quality improves with amount leached over time.

6.8 SUMMARY

A. Revegetation

1. Experimental Revegetation on Surface Disturbed Sites

Experimental Revegetation Plot R-1, located on a northwestern exposure at 2164 M (7100 ft.), had an average vegetative cover of 63.2 percent for all species over the sixteen treatment combinations tested. This represented a decrease over the 85.2 percent cover recorded during 1983 and was primarily the result of decreased cover of grass species.

Planted wheatgrass (Agropyron) species continued to provide the majority of cover for planted grasses, with green needlegrass (Stipa viridula) and Indian ricegrass (Oryzopsis hymenoides) being subordinate species. Planted grasses accounted for an average of 27.1 percent cover in 1984 whereas invader species averaged only 0.04 percent. A statistical comparison of 1984 cover data for planted grasses between treatment combinations revealed no significant differences. Invader grass species were not present in sufficient numbers to produce ANOVA results. Grass cover for planted species in 1984 was found to be higher than for all other years of record except 1983. Cover of invader species was the lowest recorded since studies began in 1976. There did not appear to be any measurable effect of grazing upon the cover of grasses; however, it was evident that aboveground biomass was lower on grazed areas as compared to fenced control areas.

Cover of planted forb species was 27.2 percent during 1984, which represented a slight increase from the 23.8 percent recorded in 1983. Invader species decreased from 4.5 in 1983 to 1.5 percent in 1984. Comparisons of forb cover among treatment combinations for 1984 data showed significant differences based on mulch for planted species and block for invader species. The cover of planted forbs was highest on no mulch treatments. Cover of invader forb species was highest on Block 1, which remains fenced. Consequently, after one year of grazing, there did not appear to be any apparent effect of grazing upon cover or composition of

forb species. Cicer milkvetch (Astragalus cicer), Lewis flax (Linum lewisii), and yellow sweetclover (Melilotus officinalis) continued to be the most prominent planted forb species.

Cover of planted shrub species decreased slightly from 7.3 percent in 1983 to 6.7 percent in 1984. No significant differences were evident among treatment combinations based on 1984 data. Big sagebrush (Artemisia tridentata), winterfat (Ceratoides lanata) and rubber rabbitbush (Chrysothamnus nauseosus) continued to be the prominent contributors to shrub cover.

Cover for all species over all treatment combinations on Plot R-2 was 56.4 percent. Unlike Plot R-1, this represented only a slight decrease relative to 1983 when cover averaged 62.0 percent. It is unclear why cover decreased on both R-1 and R-2 when precipitation remained high during growing season. The southerly exposure of Plot R-2 was expected to receive greater insolation than at Plot R-1, which in turn would result in higher evapotranspiration and reduced plant available moisture. One would expect cover to decrease more on R-2 than on R-1 if moisture were a limiting factor. This was not the case; therefore, something other than moisture seemed to be limiting growth during 1984.

Wheatgrass species and Indian ricegrass were the main contributors to cover of planted grasses, which averaged 19.4 percent for 1984 as compared to 21.8 for 1983. Cover of invader grass species also decreased relative to 1983 (0.4 versus 2.7%). No significant differences in cover among block, mulch or fertilizer main effects were noted for either planted or invader species during 1984. No measurable differences in cover of grass species were evident between grazed and ungrazed areas.

Cicer milkvetch and Lewis flax were the primary contributors to cover of planted forb species, which average 14.5 percent during 1984. Cover of invader forb species remained the same as for 1983 (2.2%). Based on 1984 data, no significant effects were noted relative to block, mulch or fertilizer main effects were noted during 1984.

Rubber rabbitbrush, winterfat and fourwing saltbush (Atriplex canescens) were the primary contributors to cover of planted shrub species which averaged 18.7 percent during 1984. Broom snakeweed (Gutierrezia sarothrae) was the only invader species encountered, with cover averaging 1.2 percent. No significant differences in cover among block, mulch or fertilizer main effects were noted during 1984.

Conclusions regarding the use of mulch and/or fertilizer for RBOSC revegetation efforts, as based on studies at Plots R-1 and R-2, were discussed in MDP Monitoring Report 11 (RBOSC 1983) and were not altered by the 1984 results. The continued high cover of grasses, forbs and shrubs in 1984, apparently due to yet another high precipitation year, illustrated that planted species may form rather closed stands of vegetation given adequate moisture. However, slight decreases in cover for grass species during 1984 as compared to 1983 seemed to indicate that something other than moisture was limiting their growth. When closed stands are formed by highly competitive species, the movement of invader species from surrounding plant communities into revegetated areas is inhibited. Because invader species can be beneficial to revegetation efforts by increasing species richness, management techniques such as grazing of reclaimed sites may prove useful in long-term maintenance of revegetated areas. After one year of grazing, however, no such effects were evident.

2. Experimental Revegetation on a Simulated Processed Shale Disposal Site

Cover of grass, forb and shrub species averaged over all treatment combinations on Plot R-3 was 70.4 percent on the control (no processed shale) portion of the plot and 77.6 percent on the treatment (underlain by processed shale) side.

Planted grasses accounted for 32.8 percent cover for all treatment combinations while invader species contributed 4.3 percent cover. Wheatgrass species continued to be the predominant planted species, whereas crested wheatgrass and cheatgrass (Bromus tectorum) were the more abundant

invader species. Only one significant difference in cover of all invader or all planted grasses among treatments was noted during 1984. In this instance, invader grasses were shown by ANOVA results to be influenced by mulch; however, Duncan's Multiple Range Test results did not confirm any differences. Cover of planted grasses in 1984 was the highest of any year since studies were initiated in 1976.

Cover of planted forbs averaged 14.6 percent over all treatment combinations during 1984, which is the highest cover noted since estimates began in 1977. Invader forb species contributed an average of 1.1 percent cover during 1984. Statistical comparisons of forb cover showed no differences between the treatment combinations tested. Cicer milkvetch, the dominant planted forb species, continued to compete favorably with planted grasses and shrubs; however, most other forbs have not done nearly as well. Using additional, more competitive forb species or reducing the seeding rates for wheatgrass species would improve the success of forb species.

Planted shrub species, primarily winterfat and fourwing saltbush, contributed 20.2 percent cover averaged over all treatments on Plot R-3. This represented an increase in cover relative to 1983, and was the highest shrub cover recorded since 1977. Invader species accounted for an additional 1.2 percent cover, which was a slight increase from the 0.8 percent recorded in 1983.

B. Mule Deer Habitat Modification Study

Results were mixed as to the potential benefits of the treatments tested on the mule deer habitat modification study site. After four years, cover on rotochopped portions of the perpendicular oriented area were lower than non-chopped areas but this was not the case for corridors oriented parallel to the wind. The cover on seeded areas was not significantly different on rotochopped corridors than for non-chopped portions of the site. No effects of fertilization upon cover were evident from the 1984 results; however, both planted and non-planted species in fertilized areas may have been more palatable as a result of this treatment. The preferential use of

rotochopped corridors and/or planted species therein by mule deer could not be ascertained by study results.

C. Shrub Growth Enhancement on a Simulated Mine Site and/or Disposal Pile Bench

1. Shrub Survival

The only species which had 100 percent survival was New Mexico black locust. Serviceberry, fourwing saltbush, New Mexico foresteria and skunkbrush sumac experienced some additional mortality in 1984 as compared to 1983 with fourwing saltbush having the highest mortality of all shrub species tested. Survival of serviceberry and fourwing saltbush appeared to be related in part to use by deer whereas rabbit use may have contributed to the mortality of oldman wormwood. Overall shrub survival was highest on Row C located on the bench and this may be related to protection afforded shrubs by deep snowpack during the winter.

2. Shrub Growth

Overall shrub growth was greater in 1984 over that recorded in 1983. Species exhibiting substantial increases based on the plant height/plant diameter index were Apache plume, fourwing saltbush and New Mexico black locust. Only fourwing saltbush approached the desired index rating of one; however, due to high mortality of this species, it is uncertain if it would be suitable for providing wildlife cover over the long term.

3. Reclamation Success

Cover on seeded areas of the bench ranged from 29.0 to 40.7 percent. There were no apparent differences between deer excluded and deer accessible portions of the site. Cover was slightly lower on areas without topsoil as compared to areas where topsoil was reapplied after construction.

D. Study to Alter Natural Succession after Fire for Enhanced Deer-Livestock Forage

This site was monitored in 1983, with results being reported in MDP Monitoring Report 13 (RBOSC 1984). The status of this study will be assessed during the 1984 field season.

E. Comparison of Inhalable and Total Suspended Particulates

PM_{10} monitors (Hi-Vols fitted with Wedding PM_{10} inlets) were colocated at Sites 1 and 3 with TSP monitors. In addition, a PM_6 monitor (Hi-Vol fitted with a Wedding PM_6 inlet especially commissioned by the American Mining Congress) was colocated with the TSP and PM_{10} monitors at Site 1.

Measured particulate matter concentrations during 1984 were quite low, with a maximum annual and 24-hour concentration of 8 and 41 ug/m^3, respectively, recorded by one of the TSP monitors. This is primarily a function of the low activity level around Tract C-a.

Second highest 24-hour concentrations at Site 1 during 1984 for TSP, PM_{10}, and PM_6 were 26, 12, and 10 ug/m^3, respectively. The annual geometric means for PM_{10} at Sites 1 and 3 were 57 and 53 percent, respectively, of the annual geometric means for TSP at the same sites. The annual geometric mean of PM_6 at Site 1 was 41 percent of the annual geometric mean of TSP at Site 1.

The PM_{10} and PM_6 had roughly symmetrical distributions around the mode, while the TSP distributions were strongly skewed toward higher concentrations. Correlation coefficients between the TSP, PM_{10} and PM_6 data sets were relatively high (0.63 to 0.87).

F. Effects of Surface Discharge on the Alluvial Aquifer

The primary effect of surface discharge upon the alluvial aquifer seems to have been a rise in the water levels and the leveling out of seasonal fluctuations within the aquifer. However, saturation of the alluvium, as a result of high precipitation and/or snowmelt, has also been noted during the last several years when surface discharges have not taken place.

G. Run-of-Mine Lysimeters

Leachate data for 1984 indicated that conductivity increased directly with the raw shale depth through which the moisture passed. However, 1984 conductivities were appreciably less than those recorded for 1983, indicating that leachate quality can be expected to improve with time and with the quantity of leachate water passing through the system.

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